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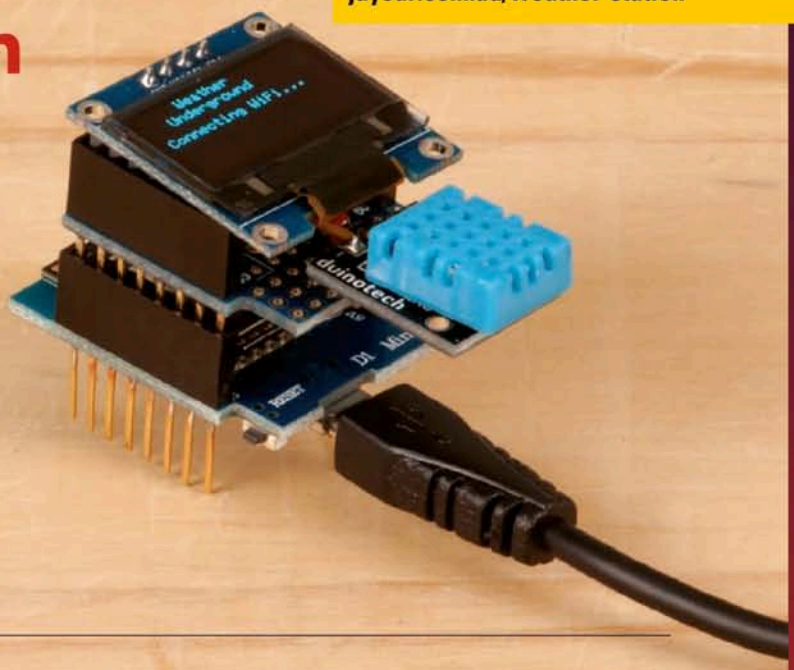

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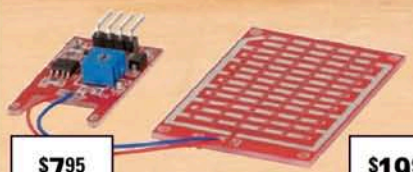

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Editorial Viewpoint

I, for one, welcome our new farm robot overlords

After reading the article on agricultural robots in this issue, some readers may be concerned about the job losses resulting from their inevitable use on Australian farms. But increased automation on farms is on-going and is desirable, for a number of reasons.

There are plenty of jobs available on Australian farms (siliconchip.com.au/link/aak1) but very few people available to do the work. You can understand why: who wants to live out the back of Woop Woop or work in the hot sun all day? Robots, however, generally don't complain about their employment conditions!

And if you're concerned about the pesticides, herbicides and fertilisers used in agriculture, you will be pleased to hear that the technology described in our article should lead to a reduction in the use of all of those chemicals.

That's partly because robots allow these chemicals to be used in a much more targeted manner. For example, robots can roam the fields, spraying individual weeds so that farmers don't have to spray the whole crop. Some can even kill the weeds without needing any chemicals at all. We also describe technology which allows fertiliser to be applied to the plants which need it most.

Another technique for increased pest and disease resistance is known as "inter-cropping" but this is generally only feasible in countries with cheap labour. But research from the University of Wageningen in The Netherlands mentions that robot technology could make this technique practical on a larger scale, as is necessary in a vast country like Australia (see siliconchip.com.au/link/aajz).

Another important modern farming technique is "no-till" farming which has become widespread in Australia over the last couple of decades. By reducing or eliminating tilling, soil erosion is reduced, water retention is improved and the remnants of the last crop help to fertilise the next one.

But one of the problems with no-till farming is that it relies on increased use of herbicides to kill weeds, and with weeds now becoming resistant to herbicides, farmers may need to go back to tilling to keep them under control (siliconchip.com.au/link/aak2). The aforementioned weed-killing robots may help solve this problem too.

The bottom line is that continually improving farm technology should allow food to be grown in a manner which is far more sustainable and better for humans and the environment. In my opinion, this sort of technology is far more important to society than autonomous cars, which have been getting a lot of attention and investment lately (to the tune of hundreds of billions of dollars in the last few years).

Agricultural technology is also easier to roll out on a wide scale since farms are a much more controlled environment. And it will have a far greater positive impact on society if it means a cheaper, fresher and more plentiful food supply. So more investment in this area would be very beneficial.

Australia needs to be at the forefront in developing agricultural technology. With our limited rainfall, huge areas under cultivation and limited rural workforce, we need to actively develop and use the technology in order to reinforce our position as a major food producer.

Nicholas Vinen

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MAILBAG – your Feedback

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First-hand experience of ANU's Homopolar Generator

I read your article on Railguns and Electromagnetic Launchers by Dr David Maddison in the December 2017 issue with interest (siliconchip.com.au/Article/10897).

Your readers may be interested in some details regarding the image of the ANU Homopolar Generator included in the article, at the bottom of page 16.

Although the image of the HPG is small, it shows three very interesting physical phenomena. Sir William Slim's hand is in such an unusual position because he has just launched an aluminium saucepan lid along the lower outer edge of the upper magnet, visible above the heads of the two figures on the left.

Aluminium being paramagnetic, once launched it continued in a circular path around the circumference of an imaginary cylinder between the outer edges of the upper and lower magnets, in effect levitating in a slowly descending spiral until it came to rest on the edge of the lower magnet.

It was astonishing for me to observe; I was the 8 or 9-year-old son of one of the electronics technicians involved with the project. Equally astonishing was to see the steel ring pictured in front of the fourth figure from the left effectively lightly floating on one corner.

Also, what appear to be two vertical lines along the front face of the ring were in fact sculptures of 1-inch or so diameter steel balls which I'm certain from memory maintained more complex shapes than vertical lines.

Not only was I privileged in my early years to see so much of this early work at the Research School of Physical Sciences, I later went on to join the Homopolar Generator Group as an engineering Technical Officer at a time the machine supplied energy to the railgun, high field magnet and laser experiments and I remained to see it dedicated to fusion research and the LT4 Tokomak.

As an aside, a large part of the success of the HPG was a result of the very low friction of the rotors spinning on air bearings.

Each 40-ton rotor was supported on a 0.004-inch (0.1mm) air film supplied by two 425HP axial flow turbo-compressors rotating at 18600 RPM. The journal and thrust bearings in the compressors were Michel tilting pad types.

Rob Parkes,
Abbotsford, NSW.
ANU Mt Stromlo Observatory 1961-1968, ANU Research School of Physical Sciences 1974-1984

Missing high-voltage warning in Heater Controller article

I think that a very clear warning should have been included with the Thermopile-based Heater Controller article in the April 2018 issue (siliconchip.com.au/Article/11027) due to the potentially lethal voltages that exist in the circuit.

Some may believe that since there is a 5.1V supply in the circuit, it is safe to touch. The 5.1V supply voltage is in fact at 230VAC mains potential.

Response: a warning similar to that on the circuit of the Speed Controller in the March 2018 issue should have been included on the Heater Controller circuit. A warning has already been added to the online version.

Cardboard fix for older radios

I have a Philips Malibu PS6 portable AM radio made around 1968 but it doesn't work. Rather than trying to fix it, I purchased a "cardboard radio" kit from Jaycar (Cat KJ9021) and mounted the circuit board inside the PS6 case. It still looks vintage but now sounds so much better than my other old transistor radios and it will now tune both AM and FM!

I shortened the plastic stand-offs and moved them to the other side of the board to allow it to sit deep in the case so that the variable resistor shafts sit into the holes drilled in the case.

The original leather outer case for the radio is very 60s chic so I didn't want the dials sticking out of the back of the case.

The board was positioned so that the large screw holding the two case halves together goes through an empty part of the circuit board. I connected the original rotary on/off switch in series with the new circuit power supply so that I can turn it on or off from the top of the radio.

The cardboard radio telescopic antenna fitted perfectly and sits so well that it looks very original (as the PS6 was AM only, it just had a ferrite rod antenna). I also drilled a hole in the bottom of the case to access the AM/FM switch.

I replaced the original tiny earplug socket with a stereo plug connected from the top of the audio pot through a capacitor. It sounds quite good.

It was a tight fit getting this board into the Philips portable radio but it would be brilliant in a larger old portable or table radio case with room to fit a larger speaker.

Dave Dobeson,
Berowra Heights, NSW.

Proposal for reducing sparky electrocutions

There continue to be electrocutions of licensed electricians who attempt to connect a Neutral wire to a Neutral bus bar, not realising the Neutral wire can be at mains potential. A recent example in New Zealand was a sparky who tried to finish a job and continued into smoko but his mates had turned the power back on during his break to boil the jug.

Some years ago, I came across an attempt to legislate RCDs in place of pole fuses, the legislators apparently being unaware that the idea could not work in a Multiple Earthed Neutral (MEN) system. But the need for improvement is there. Electrocutions will continue while RCDs are on the load side of the bus bars.

Training for electrical work should be cheaper and easier

I am from an era when electricians who had completed their training could keep their license for a lifetime. Changes have occurred since the Home Building Act of 1989 was introduced.

There should be a provision for Engineers, Technical Officers and Technicians with suitable training to do their own electrical wiring for research and development purposes.

It is totally unsatisfactory for an Engineer with the requisite experience and training to need to pay an electrician to wire up their research project, especially since there is a risk of information on their new design being disseminated due to the introduction of third parties into the design process.

I also think that the cost of maintaining a current license for electricians has become excessive and that is unfair. One needs to periodically go back to TAFE and pay for the Statement of Attainment for a course that is essentially a summary of the Australian & New Zealand Standard AS/NZ 3000-2007 (463 pages). This could be viewed as inappropriate government intervention in the industry.

I have made a suggestion to the NSW government for a new course for licensing technical specialists to allow them to do some of this work. The course is a Graduate Certificate in Electrical Licencing and Safety which would result in a six-month license for a cost of around $49 each time (it currently costs hundreds of dollars).

The need for a refresher on the wiring rules every five years is not a big ask for the specialist to keep up with change. If the NSW government does not help our specialists to be legally able to work on high voltage in research, manufacturing and/or service areas, this will prevent Australia from having a competitive workforce. The 1989 Act needs to be reviewed this year.

Gary Jackson, Qualified Engineer, Radio Tradesman and Electrician (NSW).

I propose the following changes to residential wiring to reduce the chance of such electrocutions happening in future.

Currently, the Neutral and Earth bus bars are joined with a removable link. On the Neutral bus bar, we have the incoming Neutral from the mains supply, the Neutral connection to the residence (via the RCD) and the power meter Neutral connection. On the Earth bus bar, we have the residential Earth wiring, the Earth stake and the metal meter box connection. Normally these are joined; it's when the junction is removed that danger exists.

I suggest instead that the incoming mains Neutral connections and power meter Neutral be connected directly to the Earth bus bar and the RCD's Neutral leg be used to join the two bus bars together, in place of the removable link.

This way, if the connection is broken, the RCD will still trip if anyone makes contact with the Active wiring in the residence, including any Neutral wires which would then be at Active potential.

With the normal connection, the RCD will still do its normal job and since we use the MEN system, having the incoming Neutral line connected straight to Earth should not cause any problems.

I am hoping SILICON CHIP readers will be able to point out any flaws in my plan or find any other ways to improve it.

Stephen Butcher,
Masterton, New Zealand.

4K free-to-air TV may be coming

ACMA is testing DVB-T2 digital TV transmissions between April and June. Current DVB-T Digital broadcasts use 64 QAM which means that every subcarrier cycle can represent six bits of information while the new DVB-T2 standard uses 256QAM, which basically means one byte per cycle; pretty impressive.

DVB-T2 also uses more advanced error correction, which all adds up to slightly more than double the data rate compared to DVB-T (so they say!). That, plus H.265 (HEVC) compression, is supposedly going to make 4K TV broadcasts possible. You can read more about the QAM process in our primer on Digital TV: siliconchip.com.au/link/aajw

We're hoping to get a DVB-T2 set-top box from one of our suppliers to try out during this testing period.

Keith Walters,
Technical Manager,
Jaycar Electronics Group.

Autonomous vehicles will not stop accidents

I agree in principle to J. Williams of Elanora (Mailbag, March 2018, pages

12-13) and the comments about autonomous vehicles, proprietary software and "rights to repair". However, I would like to respond to a couple of points.

Would an autonomous driving computer be safer? It is well known in space exploration that while space probes and satellites are very good at doing specific tasks, a person is much better at responding to unexpected situations.

For example, consider the situation when there is a fault in the drivetrain of an autonomous vehicle. The computer senses an over-speed condition and applies the brakes and lets off the accelerator but the throttle is stuck. The vehicle might lose traction due to the simultaneous wide-open throttle and heavy braking and could leave the road.

A human in the same situation might realise what's going on and switch the engine off or put the transmission into neutral, to allow them to come to a safe stop.

Or consider that there may be children on a traffic island/median strip. They are moving parallel to the road, so the autonomous vehicle ignores them and continues at full speed. But then one steps out onto the road suddenly, giving the autonomous vehicle insufficient room to brake to avoid the collision. A human driver might recognise that the children are at risk and slow down beforehand, thus preventing the accident.

It isn't what the computer has been programmed to do that is the issue in these cases, it is how it responds to unexpected situations. And adding to these problems is the question of, when such an accident does occur, who sues whom afterwards?

Also, I must strongly disagree with the comments about "The fact is that 99% of accidents are due to human (driver) error". That statement is just plain wrong!

I have worked in Emergency Services and I have trained and worked in a road crash rescue team. My personal experience and the opinion of others I have spoken to with similar experience is that while driver error is a factor in most crashes, it is rarely the cause of the accident.

For more than 50 years in the aviation industry, "pilot error" was a leading cause of crashes but pioneering work on what is known as "human factors" by Dr James Reason proved otherwise. He demonstrated that many accidents are the result of multiple events, none of which would cause an accident in isolation but in combination, lead to disaster.

Drivers make mistakes like pilots do but there are many other factors at play. For example, a mechanical failure like a blown tyre or suspension collapse could put a driver into a situation that a race driver might be able to recover from but a learner would not.

It would be unfair to then say that the crash was due to driver error since you could not expect the average driver to know what to do in that situation. And it's doubtful that a computer which is designed to drive in a cautious manner under normal conditions would be able to react appropriately to such an event either.

Andrew Pullin,
Wodonga, Vic.

TV channels should be restacked again

We now have HD versions of the primary TV program streams on channels 20, 30, 31, 50, 60, 70, 80, 90 and 13. Blurry SD versions are on channels 2, 3, 32, 5, 6, 7, 8, 9, and 10. So if you think "I'd like to watch channel seven" and press 7 on your remote, you get the fuzzy version even if you have an HD TV.

Why don't the TV stations swap the channels around so that the HD versions are on 2, 7, 9, 10 etc? Viewers with older digital TVs may lose reception but they will just need to re-scan to find the relocated channels.

The USA has completed a reverse auction of 600MHz UHF band TV channels where TV broadcasters get paid to go off the air or change bands. The telcos are paying for the freed channels so that they can use them for wireless broadband. They do not have such organised channel allocation that we have.

The current ACMA 5-year plan (siliconchip.com.au/link/aajx) is to do the same thing as the USA and give our spare TV channels to the telcos. There are currently only four spare UHF channels and digital radio would like channel 10 which is not of interest to the telcos.

During the introduction of UHF TV in the 1990s, the predecessor to ACMA uniquely decided to make all our UHF TV channels 7MHz wide and use the freed 470-526MHz for UHF Citizens' Band and two-way radio traffic for government agencies.

If the above frequencies were reallocated for television broadcasts, we would get channels 20-27 back and even with the loss of the other four channels, there would be enough channels to cover the country in another restack. The complication is that many receivers will need a software reload to find the new frequencies, particularly channel 20.

DVB-T2 is now in widespread use overseas. This is a new version of the DVB-T modulation we currently use. It packs more data into the same 7MHz channel. It is also capable of transmitting ultra-high definition (4K) TV along with a ruggedised lower-definition version for handheld devices.

So instead of promoting the use of apps to watch TV, the broadcasters should instead insist that the ACMA and the Customs Act be used to ban the import of receivers which cannot handle DVB-T2 modulation, HEVC video compression and xHE-AAC sound. These capabilities make little difference to the retail price and the receivers can still handle existing signals.

This will mean that in 2023, the broadcasters can switch over to DVB-T2 in UHD and the same programs will be viewable on handheld devices without data streaming charges. This will also free up the airwaves as it should reduce mobile data traffic.

I should also add that the hype about 5G broadband is misplaced; if they use the 24.25-27.5GHz band, it will not go through walls, roofs or hills.

Alan Hughes,
Hamersley, WA.

Temperature compensation for charging vehicle batteries

I read with interest H. Wrangell's letter and Nicholas' reply in the Mailbag section of the March issue (page 6) regarding modern charging schemes for automotive batteries.

Modern chargers for backup batteries have a temperature probe with the batteries and apply temperature compensation to the output voltage.

Apparently, the optimum float voltage for lead acid batteries is 14V at 25°C and reduces above that. It would appear that vehicle computers are joining in the game. It surely gets hot in the under the bonnet of modern cars.

The side effect with Telecom batteries, which have independent voltage

Victron Connect Compatible

The *VictronConnect* app lets you get live status information and configure any Victron products which either have bluetooth built-in, or are connected to a VE.Direct Bluetooth Smart Dongle.

Can you talk to your batteries?

It might sound like sci-fi but with the Victron Energy Smart Battery Sense, you can 'talk to' your batteries using VE.Smart Networking on your mobile phone.

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monitoring, is that you get a voltage alarm on a very hot day if the battery room fan is not working. So with vehicle batteries using a similar scheme, you may need to drive with the headlights on if you want "add-ons" to work as expected.

Headlight lumen output is probably a safety specification and may vary depending on system voltage, so switching the headlights on would override the voltage compensation due to temperature.

John Burns,
Katanning, WA.

Response: you are right that the lead-acid charging voltage should be reduced by approximately 3mV/cell/°C above 25°C (and increased at lower temperatures).

Keep in mind though that backup power systems typically use gel cells which have slightly different characteristics to the flooded cells normally used in cars and trucks.

Absorbed glass mat [AGM] types, often used for motorcycles and boats, also have slightly different charging voltages.

Regardless, if you do the sums, even at very high battery temperatures (eg, 70°C), the optimum charge and float voltages are typically no lower than 13.5V. So a vehicle battery that's below 13V while the engine is running is probably not being charged. We aren't convinced that this is good for battery life.

Silicon Chip staff members and their family have had car batteries last 7+ years using the traditional scheme of constantly charging to 14.0-14.4V while the engine is running. We think this is close to the practical lifespan of a battery with such a hard life (extended spans at high temperature and very high peak cranking currents).

And even if you could extend battery life slightly by letting it discharge periodically while driving, what if you happen to pull over and switch the engine off at the point where the battery has mostly discharged, then want to run the lights, radio and so on?

And what if you then exit the vehicle and leave it for several weeks, eg, during an overseas vacation? That can't be good for battery life.

Regardless, we will have to make allowances for these new charging schemes in future projects so that they work in as many different types of vehicle as possible. For example, we could incorporate a timer; as long as the battery is being charged periodically, the accessory can remain switched on.

Black level varies between PAL and NTSC

I thought the Vintage TV A/V Modulator article in the March 2018 issue (siliconchip.com.au/Article/11007) was great. There aren't too many of us (old) analog TV types left!

I have one minor correction for Fig.2 and Fig.3. The black level in the Australian PAL system has no set-up. Black (as in zero luminance) has the same level (300mV) as the back porch (where the colour burst sits) and the front porch.

The value of 7.5 IRE shown in those figures is certainly used in the USA and other NTSC systems. Also, Australian PAL uses a 70:30 ratio for a video/sync pulse amplitude of 1V peak-to-peak and not as shown.

I suspect both Figs 2 & 3 use NTSC conventions and amplitude levels. In Australian Master Controls we seldom, if ever, used IRE terminology even though Tektronix WFM graticules had both.

Kit Scally (ex MCR, TEN and SBS),
Canberra, ACT.

Response: you are no doubt correct and we believe the circuit uses the correct black level for PAL. We noticed when preparing these diagrams (which were added during editing) that there were inconsistencies between sources, with some indicating a black level of 7.5 IRE and others indicating 0 IRE. It was not clear from those sources that this was due to the difference between NTSC and PAL.

Note that the situation is even more complex (and confusing) because the discontinued Japanese version of NTSC (NTSC-J) in fact uses the same 0 IRE black level as PAL. Also, note that you can generally compensate for differences in black level simply by tweaking the TV's brightness and contrast settings. Thanks for bringing this to our attention.

Should beginners learn to program in BASIC?

Thank you again for an edition of Silicon Chip worth reading (April 2018). I read the Editorial Viewpoint with some interest as you talked about the ESP8266, the Arduino, WiFi and the C family of programming languages and I wondered about the future direction of Silicon Chip.

There is a push by the government and industry to get more people interested in science, electronics, engineering and coding (whatever that is).

However, the problem is that the push follows along the same lines as the politically correct fanatics and I wondered if those people have applied pressure to SILICON CHIP to comply. It was your comment about the C family of languages that was of most interest.

I have expressed my experience and views about programming languages in an earlier letter so I will not repeat them.

However, just lately, I have read more than two hundred posts on the Raspberry Pi forums concerning a discussion about BASIC that ran from 2011 to 2016. There were over 900 posts. Most of the participants were professional programmers and/or teachers.

The arguments were intense, both for and against. Both sides lamented the low take-up rate of programming by students and argued for or against BASIC as a teaching language.

Most of the programmers were obviously highly skilled in a variety of languages including BASIC variants and the older participants invariably began programming on early computers with ROM-based BASIC.

Nearly all mentioned the ease with which they were able to begin programming on those old machines. However, at the same time, many acknowledged that the original BASIC was not an ideal language although that is not the case with many modern variants.

In any case, there was no agreement on a suitable alternative and C, C++, Java, Pascal, Python etc were all rejected at one time by some participants.

Also, you mentioned that the availability of existing libraries was one of the advantages of the C language family. In the Raspberry Pi discussion, that did not seem to be considered much of an advantage for any language.

Many participants complained of problems originating from modules that they had imported. The conclusion was that it was better to write from scratch or only use modules that they knew were OK such as their own.

For me, the most important thing for electronics or programming is ease of understanding. Most subscribers to SILICON CHIP will have an interest in electronics as a hobby and probably have no intention of making it their profession.

If they can follow the general flow of a schematic and do not need to know the internal details of some firmware then they will be happy to make the project.

If, however, projects require a professional level of expertise in either electronics or programming, then there will only be a limited number who will want to make those projects. In fact, those with that level of expertise will probably prefer a professional type magazine instead of SILICON CHIP or perhaps both.

I will be interested to see how the magazine fares with an emphasis on using modular hardware. It has been my belief for some time that electronics can only advance by the use of hardware modules. However, as with everything, there is a good way and there is a bad way.

Like their software versions, hardware modules should be complete and not need internal modification or programming.

Configuration registers or links should be the only modifiable parts. Likewise, the interface should be a standard type like SPI, I^2C, CAN, serial, USB or Ethernet. Whatever is used, it should be relatively easy to understand and use.

George Ramsay,
Holland Park, Qld.

Nicholas Vinen responds: we have not experienced any "pressure" to publish any particular editorials or articles. Those specific comments were based on my own experiences of learning to program and subsequently working as a professional programmer.

The debate about which language beginners should learn has been raging for decades. Twenty years ago, the discussion was focused on C/C++ vs Pascal. Then Java came along and was being taught widely in universities (which I thought was a mistake at the time and I still do).

Ultimately, I believe that the language which is taught isn't that important. Learning to program is more important than learning to program a specific language. Having said that, in my opinion, there are good arguments in favour of starting with either BASIC or C.

BASIC is designed as a beginners' language and it probably is one of the easiest to learn. However, modern BA-

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SIC has gained enough features that it really isn't that far removed from C anymore, and C is used much more widely in both PC software development and embedded development. It's also easier to program (in my opinion) once you've learned its quirks.

We try to publish a mix of project articles, with some that are simple and easy to follow for beginners. However, with microcontrollers costing less than even a very basic analog IC and being capable of so much more, inevitably a lot of circuits end up being a micro surrounded by a handful of components.

That's the reality of today's industry, though. Many commercial products that you might open up would be little more than a microcontroller and a power supply since that's the cheapest and easiest way to provide the required functions.

On Kits, Hearing Aids etc

First, let me congratulate you for an excellent electronic magazine! Even when *Electronics Australia* was still published, I used to buy your magazine every now and then. At the time I thought that the publisher must have been the same as many times the same type of project appeared in both magazines in the same month.

I am concerned that Jaycar may be making some of the same mistakes as Dick Smith Electronics. Maybe the sale of electronic components and kits did not bring a huge turnover for DSE but it brought the customers into the shop and they, like me, often bought something else as well. After they stopped selling those things at DSE I never saw a need to go there anymore.

I recently built the Super-7 AM Radio receiver (November-December 2017; siliconchip.com.au/Series/321) and it was quite an effort to get all the parts, especially as they are from two suppliers. It is still not completely finished for this reason. As I live in the country, 85km from Adelaide, it is quite a problem to get a single resistor that I overlooked to buy.

Maybe SILICON CHIP could pick up the slack and produce the kits? Of course, this would be a bit more expensive – but it would be well worth the price to me to get all the parts in one purchase.

I enjoyed reading your articles on hearing aids. Unfortunately, the major suppliers do not stock Blamey Saunders' hearing aids. In-ear hearing aids are also not suitable for some people as they tend to cause an itch in the outer ear.

The biggest problem for people with hearing loss is the decline of sensitivity for high frequencies. This makes watching DVDs difficult (no normal person would watch the TV program anyhow) as the music makes most dialog inaudible.

When you reduce the volume to the point where sound effects are not painful, you cannot hear what the actors are saying!

My suggestion for a project is a sound processor that severely reduces the frequencies outside of the frequency range of the spoken word, especially low frequencies and at the same time provides an equalisation function. I tried a graphic equaliser but the reduction of low frequencies was not enough.

Sennheiser offers headphones which do this but they are quite expensive and I do not know how well it works. From the comments of your readers, it appears that the problem of hearing loss is quite common.

So a sound processor for wireless headphones would be a good idea. Maybe you could also incorporate a muting circuit if the sound level suddenly rises, as is sometimes the case when going to an ad break.

Finally, regarding nuclear reactors. I find it hard to understand that a technically-minded person like Leo Simpson considers nuclear energy, that pollutes the planet for thousands of years, to be clean energy. Nobody knows where to store the highly radioactive waste safely.

There was a technology available that could convert this dangerous waste into energy and barely radioactive waste but it was immediately banned by the then US president. Any idea why? Reading Wilhelm Reich's research on this topic might be enlightening (The Oranur Experiment). I think many readers would be interested in your answer.

Dr Horst Poehlmann,
via email.

Response: Thanks for your email and suggestion for a sound processor for the hard-of-hearing.

It is difficult for us to produce kits since doing so diverts our resources away from magazine publication which is our primary business.

As for nuclear waste, reprocessing in the USA was banned mainly for political reasons. Supposedly it was due to concerns over "nuclear proliferation" (ie, third parties getting their hands on nuclear material).

But since most nuclear waste is not suitable for weapons production, due to the presence of undesirable isotopes which cannot be easily separated out, that was only ever an excuse.

As we've pointed out in our articles, it's possible to almost entirely "burn up" nuclear waste in specially designed reactors. It's also possible to chemically reprocess it, as is done in France.

As with so many other problems these days, solutions are available but politicians are unwilling to approve them, presumably over fears of a backlash from the ignorant.

Publishing source code and using Triacs

I see that there have been a few changes in the hierarchy at SILICON CHIP. I have been a reader about as long as your publisher has been involved with magazines (not just SILICON CHIP).

There was a series of letters some years ago about publishing source code and details about the programs loaded into projects. I haven't seen much source code published in the magazine and this tends to leave projects as of interest only, with no learning associated!

Geoff Graham wrote in some detail about programming, which was excellent but I feel that people were perhaps also interested in the structure of programs rather than just the syntax.

Perhaps you could allow readers to register an account on the SILICON CHIP website and then provide a QR code or similar in the magazine to access some details associated with that particular article.

Regarding the February 2018 WiFi Water Tank Level Meter, why did you use a 10Ω resistor as the current sense resistor when a 150Ω resistor would have allowed you to eliminate one IC?

And with the March 2018 Motor Speed Controller, I don't see any noise filtering in the mains input. I would have thought that there would have been at least a token attempt.

I haven't found Triacs used for mains switching to survive very well. I ended up using back-to-back SCRs with an opto-isolated trigger which proved much more robust.

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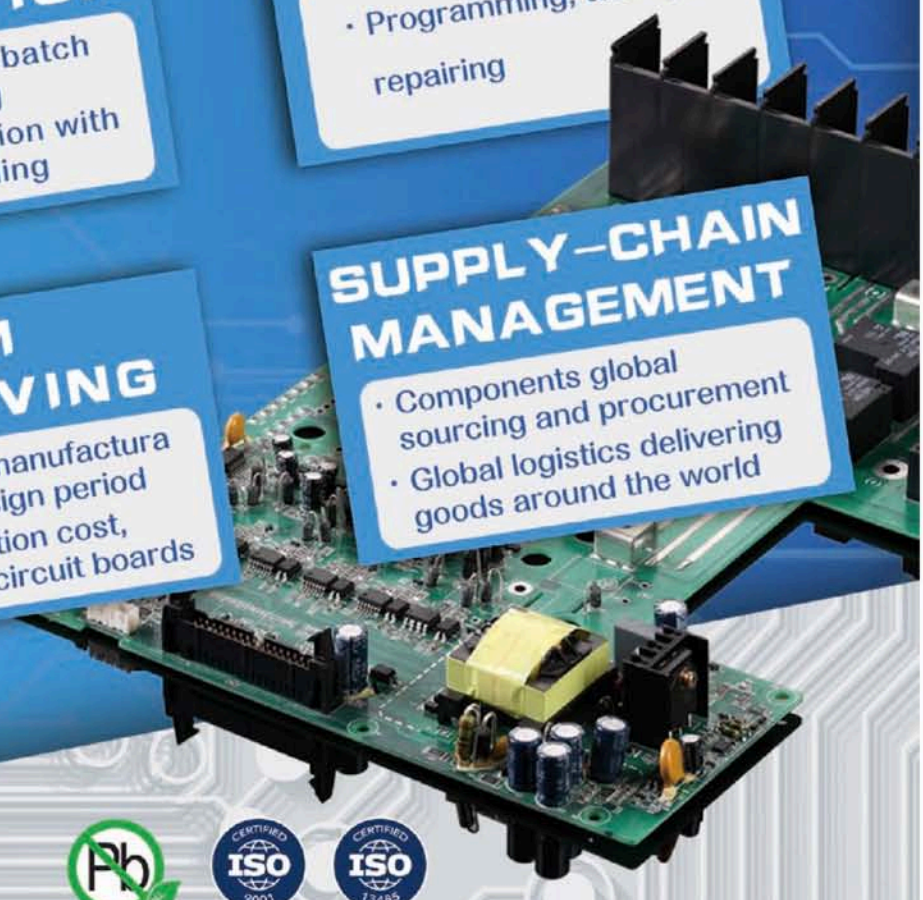

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I know space is at a premium, but wouldn't an isolated supply be more preferable?

Bill Bool,
Perth, WA.

Response: we sometimes publish snippets of source code and explanations of how the software developed for our projects works. We usually can't publish the full source code since it is too big. The code for the USB Flexitimer published in this issue is around 1000 (long) lines, not including the Microchip USB library files.

We publish the source code for virtually all our projects on our website and the downloads are free for subscribers. Interested readers should download and examine the code, even if they are not strong programmers; you never know what you might learn.

To find source code relating to an article, simply go to the SILICON CHIP website, click on the "by Year/Month" entry under the "Shop" menu, then click on the issue you are interested in. All the relevant downloads, PCBs and so on will appear.

We used a 10Ω resistor in the Water Tank Level Meter to minimise the variation of sensor supply voltage with the water level. The sensor data sheet does not indicate how much variation it will tolerate so we minimised it.

If you want to test it with a 150Ω resistor, you can simply omit the 1kΩ and 15kΩ resistors, 100nF capacitor and IC1 and wire a link between pins 5 and 7 where IC1 would be fitted.

Regarding the Motor Speed Controller, brushed motors produce so much EMI from commutation that any interference generated by the speed controller tends to be relatively insignificant.

Thus, we have incorporated a snubber network to help suppress what interference it does generate; the inductance of the motor windings has a filtering effect as well.

While it is true that an SCR with similar ratings to a Triac will tend to be somewhat more robust, the Triac we have specified for this project has such a high voltage and current rating that it should stand up to a lot of abuse.

We have used the same Triac in a number of other projects and have not had complaints about failed switching devices.

Also, it would be virtually impossible to get a full-wave controller based on SCRs (even with multiple devices) to vary the speed over such a wide range.

Gigabit networks require quality cabling

I have some comments on Dave Thompson's story of his networking problems in the Serviceman's Log column from the March 2018 issue.

Firstly, let me say how much I appreciate Dave and his column. The wide variety of his stories (and those from other contributors) is most entertaining, not to mention educational. I was most intrigued by his claim as to being a "bandwidth junkie".

As someone who lives 160km from Sydney, my options are ADSL over buried copper, fixed wireless or satellite. The wireless option is problematic as there is a big hill is between the tower and my house. I thought it would have been a good idea to put the tower on the hill! Satellite is pretty expensive, with a limited data quota.

My phone line runs 3.5km from the powered node, the last kilometre being a 40-year old bulldozer-laid twin pair. Speed checks reveal a consistent 3-4Mbit rate. I am probably fortunate that we are a two-person household and while we can stream two video programs at once, we generally need only one. Complicated web pages are a bit slower to load but not that much.

This situation gives me no problems with Netflix and other streaming services. I do however still have a bit of "bandwidth envy". It is interesting to observe what a country with a small population base can do compared with Australia.

I won't try to teach Dave how to suck eggs but I would like to relate my own experiences with Cat5e/Cat6 cables.

Ten years ago, I installed a network of five PCs in our family-run hairdressing salon. The hardware was all to 10/100 megabit specifications and worked well. Speed checks were in the high nineties.

As time went on and the salon's computing needs increased, I upgraded the motherboards. It was obvious that faster transfer rates would also help and the fact the new motherboards had on-board gigabit ports meant that a couple of new eight-port switches should do the trick.

But after this upgrade, the Ethernet speed still registered under 100Mbps. Then I read more about gigabit networks where it was emphasised that all eight wires (four pairs) in the cables had to be correctly terminated in the RJ45 plugs for gigabit operation. Since only two pairs are used in 10/100 networks, I wondered if I could have had some termination problems that hadn't been picked up originally.

That must have been the case since re-terminating all the RJ45 plugs resulted in gigabit speeds between all the computers. Tests then showed transfer rates of 700-890Mbps from hard drive to hard drive.

The slowest was the most remote PC where the signal had to pass through to switches and about 45m of cable. The networked salon software was noticeably faster after that.

Brian Wilson,
Cambewarra NSW.

Nicholas responds: I live in the Sydney metropolitan area and my internet speeds are barely any better than yours (around 5-6Mbits). So don't be too envious! The problem is not our population but the population density.

We're number 240 out of 249 in the list of countries by population density, with only Namibia, French Guiana, Western Sahara, Mongolia, Falkland Islands, Greenland and three other small islands being lower.

Ultrasonic Anti-fouling problems due to faulty PIC

I have just built the New Marine Ultrasonic Anti-Fouling Unit (May-June 2017; siliconchip.com.au/Series/312) with a single transducer, using the Jaycar kit. I am an experienced kit builder.

I carried out the initial testing and adjusted the low battery and hysteresis settings. This all went well and as I have an adjustable power supply, I checked the low battery cut-out and reset.

I did this a number of times and it all worked as described until I adjusted the supply up a third time to 14V and turned it off and then back on. The fault LED then started flashing.

The unit now starts up with the power LED permanently lit for approximately 3 seconds, then the fault LED starts flashing.

With the power off and capacitors discharged, I checked FETs Q1, Q2, Q5, diodes D9, D8 and D10 and they all appear to be OK with no shorts and forward voltages as appropriate. The main capacitor bank is not shorted.

I have tried to monitor the waveform at the anode of D9 with a newly

acquired Rigol DS1074Z. I see a short burst of 3V pulses at 5kHz. This not a square wave but more like a sawtooth with a sharp rise time and a slow decay time of approximately 1µs with 200µs between pulses.

The voltage across the main capacitor rises to about 1.6V, then starts to decay. However, if power is applied soon after switch-off, this voltage rises to close to the full supply voltage, then decays as the fault LED flashes. Note that I have not fitted transformer T1 yet.

Before I started de-soldering parts, as the PIC is in a socket, I thought that the easiest thing would be to obtain another PIC from Jaycar but they have advised that it is not available from them as a separate part.

You kindly offered to supply me with a replacement PIC. I have now fitted that and it solved the problem. I don't understand how the old chip could have caused this fault since it clearly wasn't completely dead. But since replacing it solved my problem, I guess it must have had some sort of internal problem.

I notice that you published a letter on page 99 of the December 2017 issue, from a D. B., of Sydney who had basically the same symptoms as my unit. You advised him/her that the fault is with the low-ESR capacitor(s) but perhaps it's the same PIC fault as I had.

I have subscribed to SILICON CHIP for most of its existence (and EA before that) and have built a number of its projects with no problems before this. Keep up the good work.

Lee Cockram,
Perth, WA

Modern monitor cables are a shemozzle

I work as a software developer at a small company in Sydney's CBD. Recently we purchased an Asus ZenBook computer and a Lenovo 23-inch external monitor. The computer had an HDMI port but the monitor only had a DisplayPort input, so the store sold us an HDMI to DisplayPort cable to connect them.

Back at the office, we connected them up but the monitor just showed "No input signal", even after we set the laptop to extend the Windows 10 desktop onto the external display. We tried another computer with an HDMI port but the monitor still failed to display anything. We then purchased another (longer) HDMI to DisplayPort cable but it still didn't work.

At this point, I had a thought: does the translation of HDMI to DisplayPort involve a chip embedded in the cable? If so, maybe these monitor cables are one-way. And if that is the case, we are probably trying to use them in the reverse direction to what they were designed for.

I checked the packaging that came with the cable for any hints about one-way operation, but the only information was what was printed on a sticky label on the bag: DP-HDMI. Maybe the fact that DisplayPort was shown first was a hint.

The salesman who we bought the computer and monitor from had a number of helpful suggestions but none of them solved our problem. Then he pointed out that the ZenBook also had a Mini DisplayPort connector too.

So we exchanged the HDMI to DisplayPort cable for a Mini DisplayPort to DisplayPort cable. The thinking was that such a cable would almost certainly be a straight pin-for-pin connection without any one-way electronics. Returning alone to the office, I wasted no time plugging it in.

That done, I saw that the power light on the front of the monitor was flashing green. That was unusual – it had been solid green previously. But still no picture. I then realised that the mains power adaptor for the monitor had been unplugged when I had gone to get the second replacement cable.

I was frankly astonished that the designers had bothered to arrange for a monitor to flash its power light to signal lack of mains power. Once I restored power, the monitor worked on the Thinkpad, and also on the Asus ZenBook.

Finally, after no less than four trips to the computer shop and most of my morning wasted, we had the computer working with the monitor.

I have subsequently done a lot of research on HDMI to DisplayPort cables and have found that the situation is more complex than you might first imagine.

For example, connecting a DisplayPort output to an HDMI input through a passive adapter cable won't work unless the DisplayPort device has the symbol DP++ next to it, meaning that it performs the translation to HDMI itself.

So the problem we had was probably not due to the cable having one-way electronics. It might have actually been because the cable was passive so there was no translation of the HDMI signal to the format needed by the DisplayPort input on the monitor.

I probably would have done the research earlier and figured out the problem, had the salesman not been so adamant that the combination of computer, monitor and cable should work.

Andrew Partridge,
via email.

Response: HDMI is a derivative of DVI (essentially, it's DVI and digital audio in a smaller connector) and was developed by Hitachi, Sanyo, Philips, Sony, Toshiba and others in late 2002. DisplayPort is a later standard developed by VESA in mid-2006 and adopted by Apple.

Unfortunately, while HDMI was standardised first and adopted by a number of manufacturers, it has been much slower to keep up with higher resolution displays; for a number of years, high-resolution (eg, 4K) monitors came with HDMI sockets but most computers with HDMI outputs did not support the latest standard and so could not drive them.

As a result, DisplayPort use became more widespread on PCs as well as Apple computers.

While there are some similarities between the two standards, HDMI's TMDS signalling has a swing of 1-3.3V while DisplayPort has a maximum voltage swing of 1.38V. Hence, a "dual mode" DisplayPort output (also known as DP++) is required, which can detect when it is driving an HDMI monitor and increase its voltage swing to the required range.

Alternatively, an active adaptor must be used, which contains DisplayPort to HDMI conversion circuitry and is powered by the DisplayPort output. Our experience is that these do not always work properly.

You would think that if you stick to the one standard (HDMI/HDMI computer and monitor or DisplayPort/DisplayPort computer and monitor) you would be safe. But unfortunately, there are different versions of both standards and if your computer uses an older standard than the monitor, it still may not work. In summary: it's a mess.

The bottom line is that it pays to do online research before purchasing a new computer or monitor. SC

AGBOTS (AGRICULTURAL ROBOTS)

Automation and robotics are already making farming much more scientific and productive, while reducing labour costs. But that's only a small part of the story, as Dr David Maddison explains . . .

While much has been written about robots in industry, most people would not be aware that robots are already making inroads on Australia's farms.

In fact, with the general shortage of available rural workers, in the future we will see far fewer humans and many more robots on farms.

A great deal of the work of farms is seasonal, for example, lots of workers (and machines) are needed at harvest times but not many in mid winter.

But if it were not for large numbers of young tourists working their way around Australia, many farms, particularly those involving vineyards, orchards and market gardens, would have insufficient labour to harvest their crops.

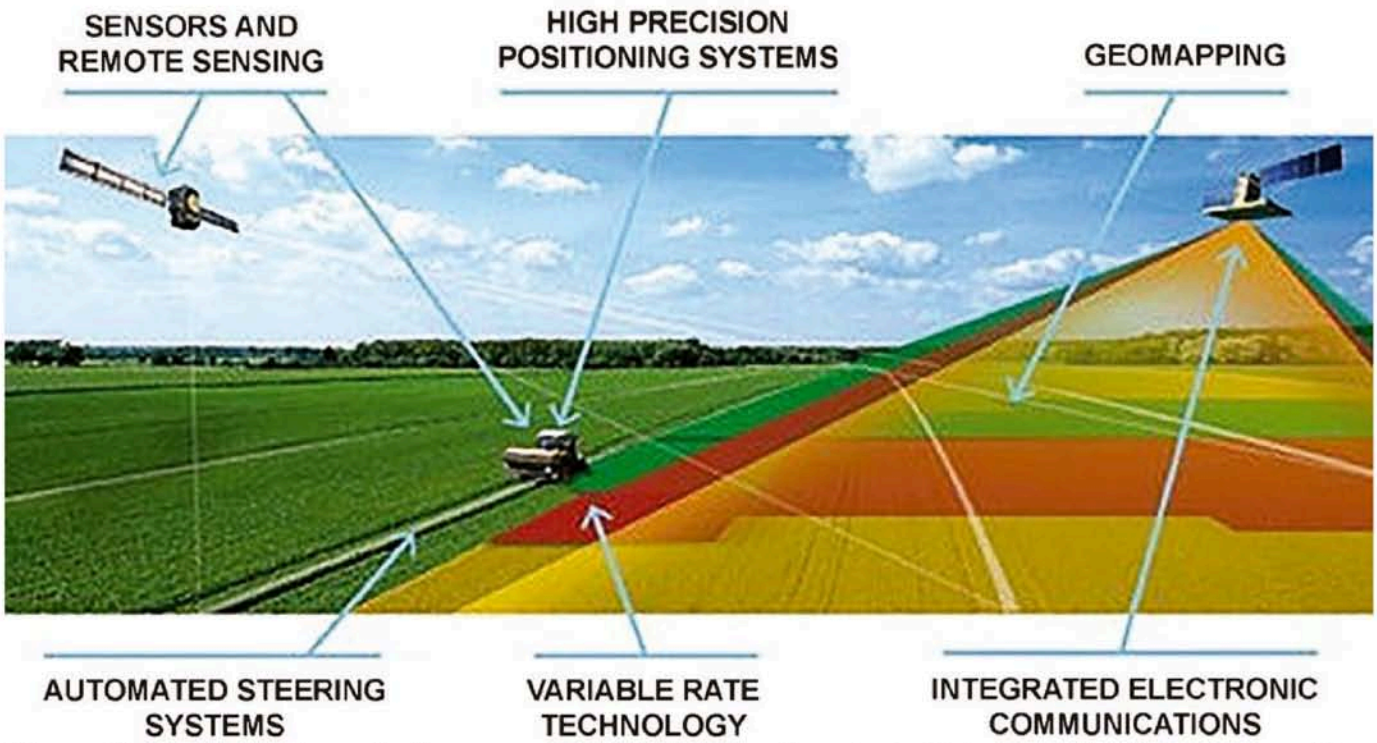
Are robots the answer?

We've seen how huge advances have been and are being made in robot technology. These robots don't simply have the potential to reduce labour costs on farms and increase productivity, they could ultimately replace most of the workers on farms – and among many other benefits, lower the use of herbicides by selective destruction of weeds and lower the amount of fertiliser needed by specifically targeting growing crop plants.

Some applications of agricultural robots are relatively easy to implement, such as harvesting wheat or corn; the machine simply follows a preprogrammed route up and down a paddock using GPS navigation.

Other applications are more challenging, such as deciding which fruit is ripe to pick and guiding a robot arm to the desired location while avoiding damage to other parts of the tree.

Or harvesting carrots, for example: machine vision dis-



This graphic shows precision agriculture concepts including the use of sensing to obtain crop and soil data, high precision guidance of agricultural machinery and robots, geomapping of fields and variable rate technology that can apply more or less chemicals as required. Note that while satellites are depicted in this image, sensing and mapping is more generally done with agricultural drones.

tinguishes between a weed and a desired plant. Weeds are either left in place or, with really advanced robots, targeted for destruction at the same time the carrot is harvested.

More complex still could be deciding which parts of a fruit tree, vine or other type of plant to prune.

And what about shearing a sheep or other animal with a fleece? That's been possible for almost 40 years, even if not widely implemented (see panel).

Agricultural robots can work around the clock and can do routine cultivation and prevent major weed outbreaks or infestations of destructive insects. Multiple robots could also be deployed, each of which would patrol a selected area for weeds or to harvest crops.

Crop monitoring

Agricultural drones can surveil crops using optical imaging at different wavelengths to obtain data about productivity in different areas. This could suggest that certain parts of a field might need more fertiliser or other treatment, determine crop maturity or count numbers and locations of animals.

Some agricultural drones can also deliver chemicals such as pesticide or herbicide to selected locations.

Apart from the applications mentioned above, agricultural robots are already being used for planting seeds or seedlings, nursery planting (planting seeds in pots), thinning out crops as they mature, environmental monitoring, soil analysis, fertilising and irrigation, herding, checking the integrity of fence lines and gates, milking cows and so on.

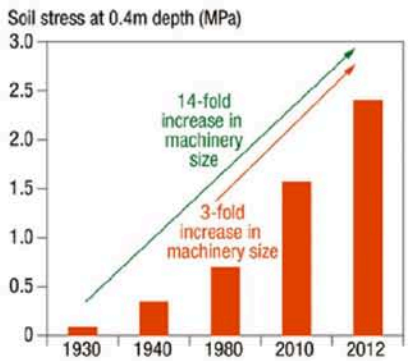
Internationally, a very large variety of different agricultural robots are either under development or in production, so we will discuss some representative examples of different types.

Categories of agricultural robots

At the most basic level an agricultural robot could be a tractor, harvester or truck which has had automated guidance installed and can therefore be operated with or without a driver. Some such vehicles are designed to be autonomous and have no provision for a driver.

There are also dedicated ground-based robots to perform tasks such as harvesting, weeding or herding.

Finally, there are aerial drones for observation or spraying.



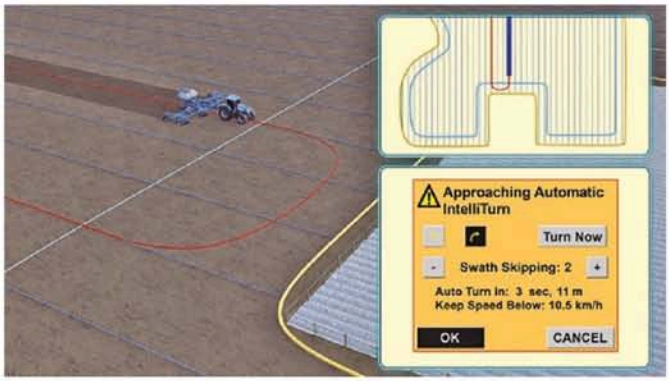
Increase in soil stress due to heavier machinery.
Image source: Australian Government Grains Research and Development Corporation

The use of agricultural robots is closely linked with the concept of "precision agriculture". This involves measurement and observation of crops to account for individual variability of plants or specific areas which may require more or less fertiliser, water, pesticide, herbicide etc.

This minimises use of chemicals and ensures more uniformity in crops. In fact, it has been estimated that at least fifty percent of agricultural chemicals are wasted; robots could make a large difference.

Large machines compress the soil

Over the years, farm machinery such as tractors and harvesters have become much larger and heavier, so that huge areas can be ploughed, seeded and harvest-



New Holland's IntelliTurn system. In this diagram the boundary fence is shown in the graphic image. The yellow line represents the path that the tractor was first driven around the boundary fence to program the system and delineate the maximum extent to which the tractor can be physically driven within the boundary fence. After the limits are programmed in that manner the system software maps out the path of the rows that are to be planted or harvested. These are indicated by the straight lines. The area between the yellow boundary line and the inner blue line in the map at the upper right of the diagram is the turning area and is not sown or harvested. The red line indicates the current path of the tractor. The bottom right part of the image shows the operator display.

Video *"IntelliTurn™ Intelligent Automatic End of Row Turn System"* **https://youtu.be/44WohoJ6D20**

New Holland NHDrive concept autonomous tractor with implement. It is based on a standard model New Holland T8 Auto Command tractor. This is made by CNH Industrial, the same corporation as makes the John Deere brand. This tractor appears like a regular tractor as it has a cab but can be used in either autonomous mode or with a driver for tasks which are not currently suitable for autonomous operation. It can be remotely controlled and monitored via a laptop computer or tablet.

The Case IH autonomous tractor with equipment in tow. There is no provision for a driver on this vehicle.

ed very quickly. However, those heavier machines mean much more loading on the soil, notwithstanding the fact that these larger vehicles have multiple larger tyres. Between 1930 and 2012 there was a 14-fold increase in machinery size with a subsequent increase in soil stress beneath the machinery's tyres of approximately six times.

This increase in soil loading causes compaction which results in areas of less-productive and even unproductive soil.

Using a greater number of smaller and lighter agricultural robots will result in greatly reduced soil compaction and hence greater productivity. In addition, having multiple smaller less expensive robots rather than one larger machine, whether it be autonomous or with a driver, allows greater redundancy in the event of a machine failure. And lighter machines can go out when the ground is soft after rain with less chance of becoming bogged.

On the other hand, smaller robots may be less productive than the larger manned or autonomous machines they might replace because they would be narrower and thus able to harvest or plant less in a single pass, as well as possibly being slower. This lesser productivity can be mitigated by having the robot work for 24 hours a day, as compared to a human operated vehicle. Or multiple cheaper robots may do the same work as a single large autonomous machine for the same or lower total cost.

Semi-automated and driverless robotic tractors

Driverless tractors, like autonomous cars, use various sensors to observe the environment, avoid obstacles and determine position etc. And like present autonomous cars, they have a human controller or external supervisor to monitor operations.

Driverless tractors have their origins in precision agriculture which was developed in the 1980s to enable farmers to more efficiently work their fields with the aid of GPS guidance. This was further developed into semi-automated tractors whereby the tractor would follow straight lines when sowing seed or harvesting but the driver would have to manually steer the tractor at the end of each seed or crop row.

New Holland's IntelliTurn system uses the tractor's guidance to follow straight lines but also controls the end of row turns which were normally done by the driver. The system can also work with irregularly-shaped fields and obstacles such as trees.

Driverless tractors were first developed around 2011 with the concept being for one driverless tractor to follow a tractor with a driver in a "follow me" mode, enabling one driver to control two machines and thus doubling labour productivity. Similarly, a harvesting machine could have a driverless truck follow for continuous collection of grain.

Today, driverless tractors are mainly divided into two types, either with full autonomy or supervised autonomy. Some driverless tractors may also have a cab to accommodate a driver for jobs not amenable to driverless mode.

Tractors with full autonomy use fixed transponders around a field for precise location with links via lasers and/or radio signals. Human controllers then monitor tractor operations from a central location. Many modern tractors can also be retrofitted for autonomous operation by using the CAN (Controller Area Network) bus system for controlling them via the addition of a computer, radio and GPS system.

CAN is the now almost-universal control bus that allows microcontrollers to communicate with the hardware to steer the vehicle and perform other operations. Most modern trucks and cars utilise the CAN bus.

In supervised autonomy, the driverless vehicle follows the vehicle with a driver and they communicate via a V2V (vehicle-to-vehicle technology) radio link. This is defined by the WAVE standard or "Wireless Access for Vehicular Environments" in the US or ETSI ITS-G5 in Europe. It operates in the WiFi spectrum at around 5.9GHz.

Autonomous tractors provide increased fuel efficiency due to driving the minimum necessary distance and reduce wastage of seed when sowing as the rows are planted accurately. Sensors mounted on tractors can measure soil and crop conditions before and after harvest time. They can also operate at night, stopping only to refuel and for routine checks.

Companies currently developing and/or manufacturing semi-automated or autonomous tractors include John Deere, Case IH (both owned by CNH Industrial), Autonomous Tractor Corporation and Fendt.

Autonomous tractors require situational awareness and this is provided by a variety of radar sensors to detect metallic or water-containing objects and video cameras which transmit a live video feed back to the operator. If an object is sensed in the path of the machine it automatically stops and awaits further instructions. If the obstacle is removed, the machine will restart.

A video showing autonomous tractor concepts from CNH Industrial is: *"The CNH Industrial Autonomous Tractor Concept (Full Version)"* **https://youtu.be/T7Os5Okf3OQ**

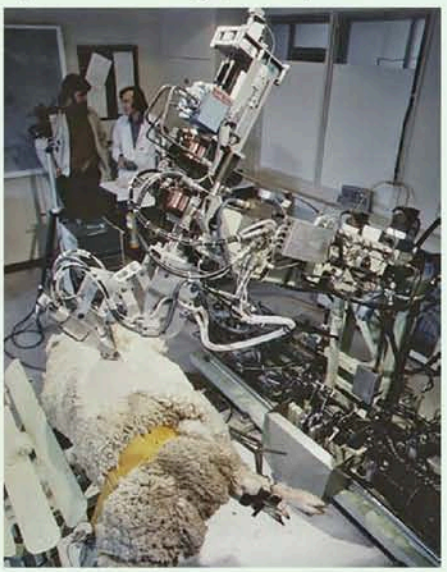
Autonomous mowers

Agricultural robots are not just restricted to commercial environments. There are now large numbers of robot lawn mowers available to the consumer. Brands and models of robotic lawn mowers include the Husqvarna Automower, John Deere, the Landroid M, the Denna L600, Lawnba Robotic Lawnmower E1800, various models from Ambrogio, Techline, Belrobotis, Exgain, Robomow, Honda, Flymo, Bosch, Viking iMow, McCulloch and Gardena.

John Deere E5 TANGO Series II autonomous lawn mower. The mower is of the mulching variety meaning that cuttings are not collected. If the battery charge becomes low it parks itself in a charging station and it is also sufficiently quiet that it can operate at night.

The sheep-shearing robot that worked well . . . but never quite made it!

A robot sheep shearer is among the most challenging agricultural robot and artificial intelligence applications. In 1979 a sheep shearing robot called The Oracle was developed by Professor James Trevelyan at the University of Western Australia but was only intended as a research prototype. It's successor "Shear Magic" (SM) clipped 400 fleeces between 1985 and 1993 with a lower injury rate to the animal than from human shearers. SM achieved commercially realistic shearing speeds by 1993.



The research was funded by the Australian Wool Industry alongside biological defleecing experiments.

A South Australian company also developed their own robot shearing technology. Just as the robots were ready, a huge financial crisis in the wool industry stopped commercialisation.

While they were never used in shearing sheds, the robots helped moderate shearers' wage claims after 1987. These benefits have far exceeded the research costs.

Nearly 30 years on, labour shortages in the wool industry have re-awakened interest. Robots may be shearing for a living within a decade.

See video: *"Robot Sheep Shearing"* **https://youtu.be/6ZAh2zv7TMM**

For example, the John Deere TANGO E5 Series II domestic mower works within a perimeter boundary delineated by a buried wire. Within that perimeter the mower moves randomly to mow the lawn, much like a robot vacuum cleaner.

There are many videos on line which demonstrate the use of robotic/autonomous mowers, over plots from tiny suburban lawns (why would you bother!) through to large turf farms.

However, some of these are merely manufacturer's marketing spiels and, while interesting, are rightly criticised for highlighting their opposition's shortcomings while emphasising their own strengths. Search for "robotic lawn mowers" on YouTube.

Robotic milking

Milking cows has traditionally been a highly labour intensive process accounting for 50-70% of labour expended on dairy farms. Cows must be milked twice every day.

The process of milking consists of the following tasks: bringing the cows to the milking location and booth, inspection and cleaning of udder/teats, attachment of teat cups to teats, extracting milk, removing the teat cups and returning the animals to the paddocks. Each cow has an electronic tag which allows a record of the milk production of each animal.

Most of the above processes have previously been achieved with a semi-automatic milking process. The most challenging process to implement was the automatic attachment of the teat cups, although this has now been achieved and is used routinely. Some manufacturers offer retrofit equipment to turn semi-automatic milking operations into fully automatic ones.

Apart from increases in farm productivity, a University of Sydney Dairy Research Foundation study found that robotically-milked cows are calmer and less stressed than conventionally milked ones.

Gives a whole new meaning to that many-decades-old advertising slogan "from contented cows . . .".

Videos: *"Australia Wide: Robotic dairy farming - Australia Plus"* https://youtu.be/ULzUCo2AlA; *"Totally automated milking - Robotic milking (1/5)"* https://youtu.be/If7iA4sMpF8 and subsequent parts in the series; and *"Lely: Happy Cows, Good Milk"* https://youtu.be/XtSIU5BCOYw

Robotic arm for milk extraction showing brush (orange and white) to clean and apply sterilising solution to teats before the teat cups are attached. They are located using laser and ultrasound position sensors.

Fruit picking robots

FFRobotics fruit picking robot arm.

FFRobotics www.ffrobotics.com is an Israeli company that has developed a fruit picking robot that has slender straight robotic arms that emulate a human picker and can be programmed to pick a variety of different fruits such as apples, citrus, peach and pears.

It is said to be able to pick the fruit without bruising and pick fruit at ten times the rate of a human picker. It utilises Robot Operating System for its basic software suite, machine vision and machine learning to learn the characteristics of particular fruits and orchards.

The robot is in the final stages of development and has been tested in Canada, Israel and the USA and is expected to move into production toward the end of 2018.

Videos at *"Automatic fruit picker demonstration by FF Robotics : IFTA 2017"* https://youtu.be/UaL3UxUclKY and *"FF Robotoics Apple Harvester"* https://youtu.be/c0y92xMl7F0

FFRobotics main vehicle containing control equipment and collection mechanism. Note the row of collected fruit ready to be loaded into the hopper.

Another company developing a robot that specialises in picking apples is California-based Abundant Robotics (www.abundantrobotics.com).

It uses machine vision to identify apples but instead of a robot hand it uses a vacuum tube to suck the fruit off the tree and into a hopper.

This machine is being trialled during picking season and alternates between Washington state in the USA and Warragul in Victoria. No release date for this machine has been announced.

Videos: *"Robotic apple picker trials continue in Washington"* https://youtu.be/mS0coCmXiYU

Abundant Robotics robot apple picker. Note the vacuum nozzle which is positioned over the apple which is then sucked from the tree.

Energid (www.energid.com) in the USA is also developing a citrus picking robot but unlike the others it uses multiple arms and cuts the stem rather than grabbing the fruit.

Energid citrus harvesting robot. Video: *"Robotic Citrus Harvesting"* https://youtu.be/Gf60au-U318

Crop and livestock monitoring, analysis, spraying and bird scaring with aerial drones

Agricultural unmanned aerial systems or drones can be used for observation of crops and livestock, spraying herbicides and pesticides and even scaring away crop-eating birds.

Information gathered by drones can be used to determine soil and plant health, fertiliser needs, location of pests and crop damage due to adverse weather.

As with other drones, agricultural drones come in two main varieties, fixed wing and rotary wing such as quadcopters.

Fixed wing drones have the advantage of longer range and duration but require a suitable place to take off and land while rotary wing types are more manoeuvrable and can easily hover or land, say for example, to spray weeds or pests that might be discovered.

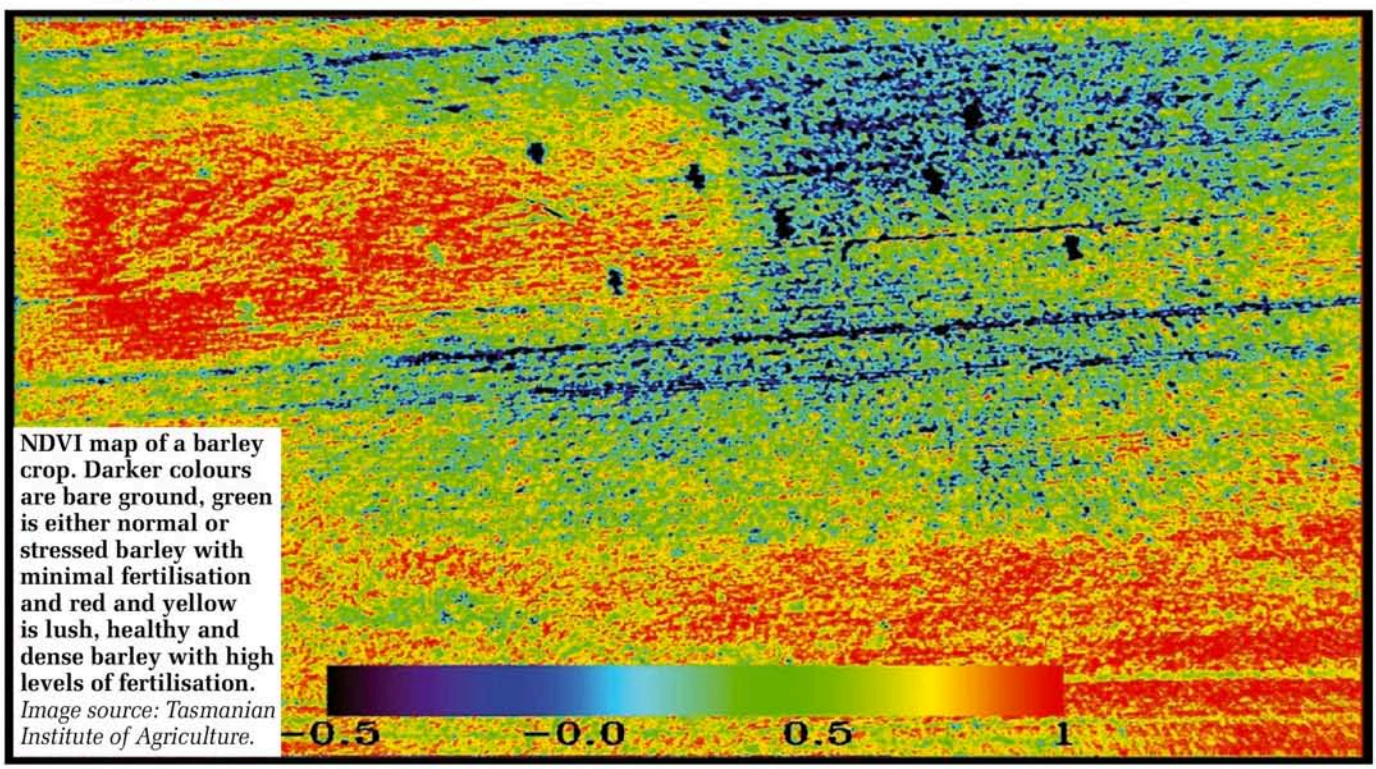
For an imaging mission one figure cited is that a fixed-wing drone can cover ten times the area of a rotary wing one. On the other hand, a rotary wing drone might be able to capture higher quality imagery due to its slower speed.

One important data parameter that can be collected by drones is the NDVI or normalised differential vegetation index. It is a measure of the difference of red light absorbed by plants and the infrared light reflected from plants. The less red light reflected, the healthier the plant. Less healthy areas of a crop can have additional fertiliser or irrigation applied.

The presence of invasive weeds can also be determined.

Scientific Aerospace (http://sci.aero) is an Australian company that makes imaging drones suitable for agricultural use.

One example where one of the company's drones was used to improve farm productivity was as follows. A 10 minute survey of a 30 hectare paddock was made to create a 3D model of the land with 20cm contours. This enabled



NDVI map of a barley crop. Darker colours are bare ground, green is either normal or stressed barley with minimal fertilisation and red and yellow is lush, healthy and dense barley with high levels of fertilisation. *Image source: Tasmanian Institute of Agriculture.*

Two Australian-made drones that can be used for agricultural applications, among others. On the left is the fixed-wing Lynx FarScight, with a mission duration of up to 3 hours. On the right is a quadcopter from the same company.
Videos: *"Lynx FarScight - Hand Launch Long Endurance High Precision Surveying Aircraft"*; **https://youtu.be/e5yYwTHs-PE** **and** *"4Scight - Safe VTOL High Precision Aerial Surveying Solution"* **https://youtu.be/YSGKpelSPXc**

the farmer to design a system of weirs and dams at appropriate locations to restore the landscape by reducing erosion and improving the productivity of the land.

The DJI Agras MG-1S is an example of an octocopter-format drone designed for variable rate delivery of liquids such as pesticides, fertilisers, herbicides or fungicides to crops.

An updated version of the earlier MG-1, it can carry a payload of 10kg or around 10 litres of liquid and can cover 0.4 to 0.6 hectares in 10 minutes. The MG-1 can deliver a spray width of 4 to 6 metres at 1.5 to 3 metres height above the crop. After depletion of the battery a new one can be inserted for continued spraying operations.

Airborne bird scaring

An interesting application of an agricultural drone is for scaring away birds from various crops. A drone is fitted with a loud speaker and flies above the crop emitting sounds that scare away birds to prevent them eating the produce.

In one application on a farm in the Ord Valley in the Kimberley of WA a bird scaring drone was flown twice per day for one hour which kept the property mostly free of birds.

It replaces multiple gas guns and other bird scaring devices as well as people on the ground chasing away birds with quadbikes. It saved $2000 per day plus saved crops.

The DJI Agras MG-1S agricultural spraying drone.
Videos: An Australian video "*DJI – Introducing the Agras MG-1"* **https://youtu.be/dCHvICOJ7mY and** *"DJI MG-1S - Agricultural Wonder Drone"* **https://youtu.be/P2YPG8PO9JU**

Aerial (drone) contract photography

While much of this feature has concentrated on the equipment needed to make life easier for farmers, another industry has emerged specialising in providing drone-based services.

For example, a company based in Canowindra (central NSW) called "Farmpix" specialises in drone photography of rural properties (among other things!) where property owners don't have their own equipment or expertise.

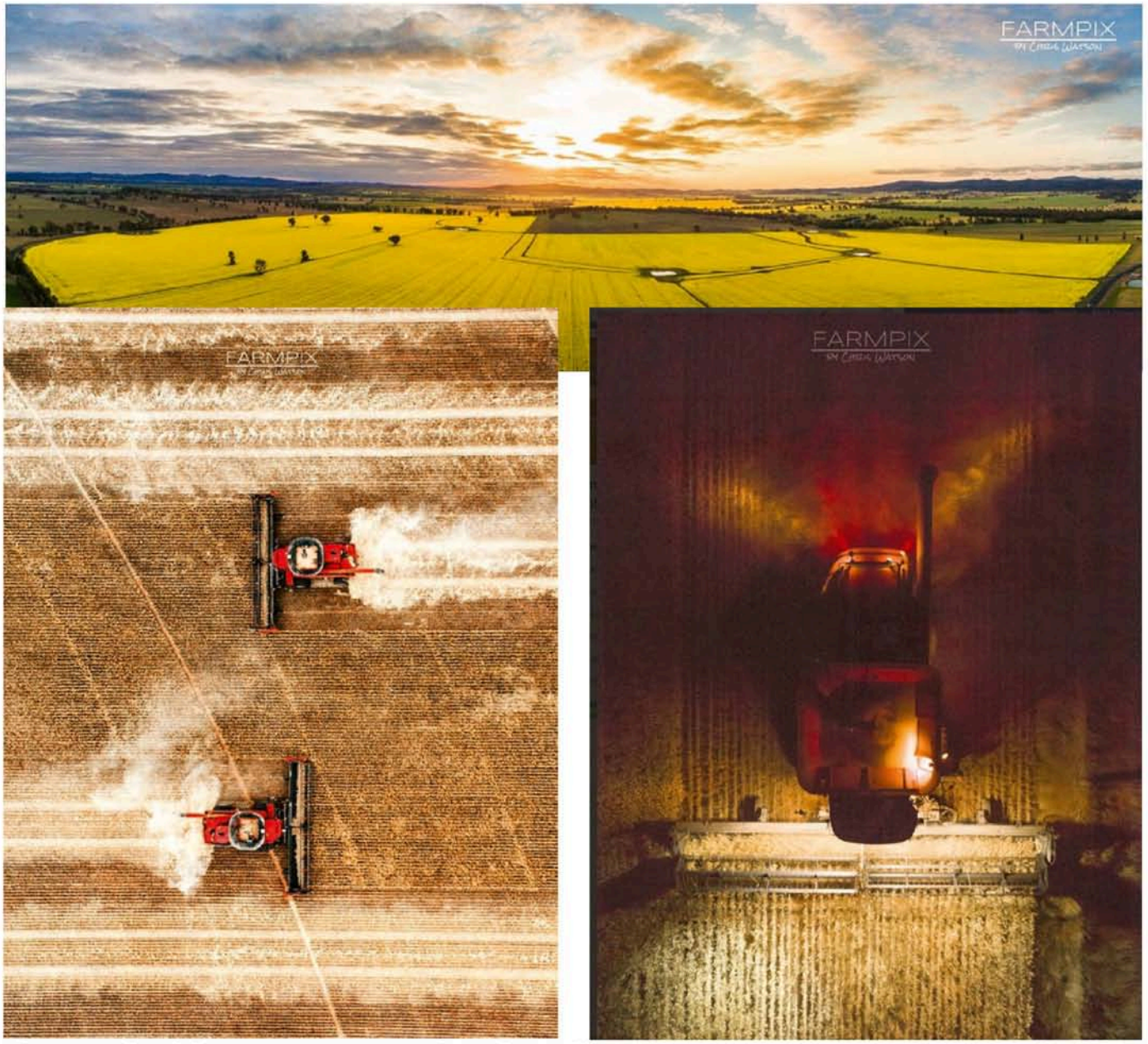
Owner Chris Watson says that he has worked throughout NSW and into both Victoria and Queensland will basically "go anywhere" a customer asks.

You can see many fine examples of rural Farmpix drone photography at **www.facebook.com/chriswatsonfarmpix** – but as an aside, while on the site check out the breathtaking drone video of Wyangala Dam and the Lachlan River in flood during September 2016!

There is a variety of farm and rural images on the Farmpix site but equally, there's a lot more you don't see as they are specifically contracted to the property owner concerned.

The three photos opposite are just some of the examples Chris has placed on his website. He also loves taking drone pictures of hot-air balloons, with Canowindra known as the hot-air balloon capital of Australia!

Bird Scarer Payload fitted to an AgStar Agriculture Drone from Rise Above Custom Drone Solutions, Smeaton Grange, NSW. This drone can be fitted with a variety of quick-swap payloads from that shown above through to multi-spectral cameras, thermal imagers, seed and bug-spreaders, a remote water sampler and can transmit live video back to a ground operator with full data telemetry from the drone. RPAS Manufacturer Training is included in the AgStar package and they can also assist in the user in obtaining government UAV Operator's Certificate (UOC) required for commercial use. (www.riseabove.com.au/agstar-precision-ag-drone)



Three examples of Chris Watson's "Farmpix" drone photos of farms and farming in NSW. And yes, he does work in the middle of the night if the farmer needs photos of night-time operations!

Disease detection in livestock

The Australian Centre for Field Robotics (ACFR) has developed a machine vision system to automatically detect lameness in dairy cattle. See video *"Automatic Dairy Cattle Lameness Detection System"* https://youtu.be/NlnLyZxv37A

Robotic weed control

In Australia it is estimated that every year $1.5 billion is spent on weed control operations and that there is an additional $2.6 billion dollar losses in agricultural production. Furthermore, many weeds have now evolved resistance to common herbicides and require more exotic herbicides or physical means such as mechanical implements, a blow torch or even microwaves to kill.

With machine vision, artificial intelligence and machine learning a robots can identify a particular weed and use the appropriate herbicide or other method to kill it and at the same time minimise the amount of chemicals used as only one particular weed plant will be treated at a time.

Agbot II is an agricultural robot developed by the Queensland University of Technology (QUT). According to QUT, "the robot's cameras, sensors, software and other electronics enable it to navigate through a field, apply fertiliser, de-

Agbot II by QUT.

tect and classify weeds, and kill weeds either mechanically or chemically, providing a tool for farmers to help reduce operational costs and efficiency losses".

It is designed to be light weight to minimise issues with soil compaction, to be low in cost so multiple robots can be utilised, to be able to communicate via the Internet so remote weed classification software can be used and to operate autonomously with multiple weed destruction methods.

Videos: *"AgBot II: A New Generation Tool for Robotic Site-Specific Crop and Weed Management"* https://youtu.be/15tovWSnJe0, *"AgBot II Trials for Autonomous Navigation"* https://youtu.be/2cAoKdJ4W2Y

Robotic "mule"

The HDT Global ground drone for delivering up to 500kg of supplies on properties in northern Australia.

Meat and Livestock Australia has recently established an arrangement with HDT Global (www.hdtglobal.com) to deploy their "ground drone" for use on six cattle stations in northern Australia.

It is the same drone as currently used by the US military to deliver payloads of up to 500kg. The drone will be evaluated for its usability and also for what attachments can be produced to improve its value on cattle stations.

Robotic strawberry harvester

Agrobot (http://agrobot.com) is a Spanish company that makes robotic strawberry harvesters. Machines can be configured with as many as 24 robot arms to pick strawberries at the desired level of maturity and the robots can be used around the clock.

The fruit is removed by cutting the stem thereby eliminating any handling damage. The fruits are detected by a colour and infrared 3D sensing system. Autonomous navigation down crop rows is achieved with the aid of a LiDAR system.

Agrobot robotic strawberry harvester. Suggested video: *"AGROBOT Robotic Strawberry Harvester"* https://youtu.be/M3SGScaShhw

Capsicum harvesting robot

Qeensland University of Technology is developing a capsicum harvesting robot. To date there has been limited success in developing such a robot but QUT is making excellent progress with initial results indicating a fruit harvesting success rate of 65% and a detachment rate of 90%.

Harvey, the capsicum harvesting robot. Suggested video: *"Harvey the Robotic Capsicum (Red Pepper) Harvester"* https://youtu.be/8rq4iSTsg68

Wall-Ye's MYCE_Vigne vineyard tending robot. Video: *"MYCE_Vigne: taille cordon de Royat"* https://youtu.be/DKTSB0LEbFQ

Vineyard tending robots

Wall-Ye (http://wall-ye.com), Vision Robotics (www.visionrobotics.com) Grapevine Pruner and VineScout (http://vinescout.eu/web) have vineyard tending robots at various stages of development or in manufacture.

Wall-Ye is a French company that makes the MYCE_Vigne. It is commercially available from €9,000 and can perform robot pruning, weeding, suckering, mowing, hoeing and is fully autonomous and solar electric powered.

Making your own agricultural robot: the Farmbot Genesis

FarmBot XL with a variety of plants in the garden. Note the longitudinal tracks on each side of the planter box and the transverse track holding the tool head at the back. The control electronics is not visible.

You can make your own agricultural robot called the FarmBot (https://farm.bot)

FarmBot is designed to tend a vegetable patch with a variety of tools for planting, weeding, watering, soil moisture sensing etc.

It's in the form of a Cartesian-coordinate robot, (one that can move in a plane in the X-Y directions).

The Farmbot Genesis model can tend a rectangular garden area of 2.9 x 1.4m with a plant height of 0.5m.

You can either purchase specially-made components or make them yourself with 3D printing from free Open Source plans.

You'll also need some standard hardware such as beams, motors and computer boards.

For its main electronics it uses a Raspberry Pi 3 and and Arduino Mega 2560 with RAMPS 1.4 shield and a camera to record imagery. The robot can be controlled via a web interface from most Internet connected devices.

A new model, the FarmBot Genesis XL, can tend an area 2.9 x 5.9m – more than four times greater than the earlier Genesis, with the same 500mm plant height.

As a rough guide, if you decided to buy a kit rather than acquire the parts yourself the kit is at the time of writing selling for US$3795 plus shipping from FarmBot (note that SILICON CHIP has not tested the kit so you should determine its suitability yourself).

Video: The latest FarmBot model *"This is FarmBot Genesis XL"* https://youtu.be/60htrqei_U0

FarmBot web-based interface on various devices.

Grapevine pruner

Vision Robotics based in the USA also have a grapevine pruner under development, see video *"Pruning Overview 2014 3"* https://youtu.be/4Ov8g0smOF4 Another offering under development is by Europe-based VineScout. The VineScout robot is expected to be on the market by 2019/20.

VineScout Robot

Nursery planting (potting robot)

Did you ever wonder how the small pots of herbs and other small plants are potted for sale to major hardware and grocery retailers? You can see the mass production process in this video: *"Transplant Systems Australia. High speed potting and herb sowing line"* https://youtu.be/cUpn6Uw6gbM

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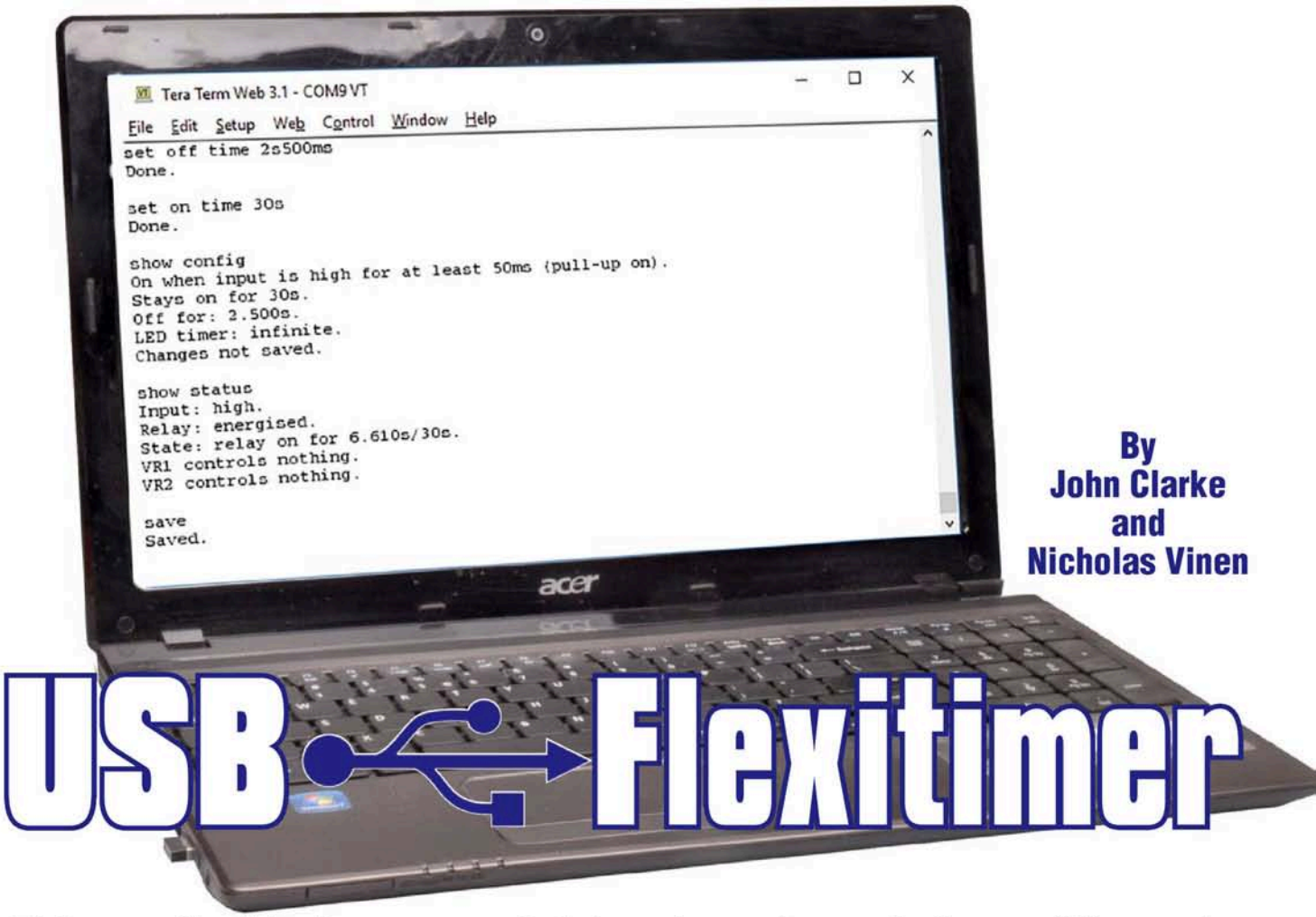
IN NEXT MONTH'S SILICON CHIP

Continuing our theme of robotics and automation on farms, we'll take a look at some of the worlds-best developments in the field particularly by two Australian universities – Sydney University and the University of New England at Armidale – and specifically the UNE's "Smart Farm".

Both were exhibitors in "The Farm of the Future" exhibition at this year's Sydney Royal Easter Show and we took the opportunity to see what they had in store for Australian farmers.

Don't miss it: in the July issue of "SILICON CHIP."



By John Clarke and Nicholas Vinen

USB Flexitimer

This very flexible timer can switch its relay at intervals from milliseconds up to many days. It can be triggered by an external pulse or set to run continuously, switching its relay on and off at a particular interval to turn an external device. It's easy to build and you can set it up with two onboard trimpots or configure it with your laptop PC via its USB port.

We have published a number of Flexitimers over the years, the last one being a PIC-based unit described in June 2008. It was programmed with an array of jumper links which gave a lot of flexibility but it required some mental agility to get the timing intervals you wanted and it has now been discontinued.

Our new Flexitimer also uses a PIC microcontroller but you can program its various time intervals with two onboard trimpots or with your laptop PC via the USB port. That makes it easy to set precise intervals and allows those intervals to vary over a very wide range, from milliseconds to days.

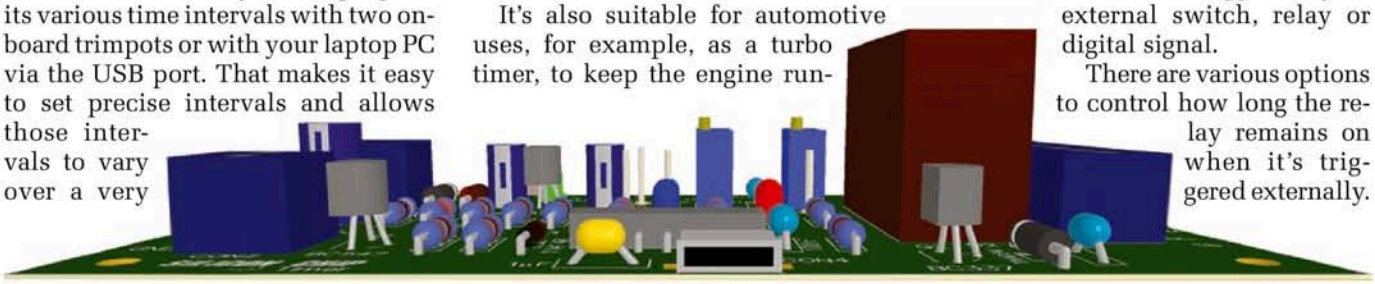
Timers like this one are popular because they can be used in so many different situations.

For example, they can be used to switch on a light or a fan for a fixed period with the single press of a button. Or it can be used to switch power on to a device periodically, eg, open a solenoid valve for a minute every hour or power up a radio transmitter for a few minutes now and then.

It's also suitable for automotive uses, for example, as a turbo timer, to keep the engine running for a few minutes after you switch the ignition off, allowing the turbo to cool down. In fact, we won't even try to think of all the different uses you could put it to because there are simply too many to list.

It has an onboard DPDT relay, with 5A-rated contacts, which is switched on and off at the programmed intervals. It can run in a continuous loop, switching on and off at pre-defined intervals, or it can be triggered by an external switch, relay or digital signal.

There are various options to control how long the relay remains on when it's triggered externally.



Previous Flexitimers:

Flexitimer by Rob Evans – *Electronics Australia,* March 1991
Flexitimer Mk2 by Rob Evans – *Electronics Australia,* August and September 1995
Flexitimer Mk3 by Jim Rowe – *Silicon Chip,* August 2005 (siliconchip.com.au/Article/3145)
PIC-based Flexitimer Mk4 by Jim Rowe – *Silicon Chip*, June 2008 (siliconchip.com.au/Article/1847)

These are detailed below.

The two trimpots are optional and if fitted, you can use them to adjust the time periods without needing a computer. The functions and ranges of both potentiometers are configurable via the USB interface. You can leave them off the board if you prefer to use the USB interface to change the timings.

While we've tried to make the unit easy to set up, we also wanted to make it truly flexible so that it can be used in the widest possible range of applications.

So it has quite a few different options which should allow you to set it up to suit virtually any circumstance. But you don't have to use them all; you can keep the settings simple if that suits you.

This is actually the fifth iteration of the Flexitimer – the first one was published in the March 1991 issue of Electronics Australia, with the most recent being the Flexitimer Mk.4, as noted above, published in the June 2008 issue.

(See the panel above for a list of all the previous Flexitimer projects.)

This one is better in just about every way, having a wider range of time settings, better accuracy, easier set-up and much more flexible options.

It uses a similar number of components and is around the same size. The power consumption of the new unit is lower, especially when the relay is not energised and it includes extra indicator LEDs.

Circuit description

As shown in Fig.1, the circuit is based around PIC16F1455 microcontroller IC1 which has a built-in USB interface for programming it. It also has an internal analog-to-digital converter (ADC) to sense the position of the optional trimpots, VR1 and VR2, which can be used to adjust the timings.

The USB D+ and D- data pins (pins 13 & 12) are connected directly to the USB socket, CON4. The USB +5V rail is connected to the micro's 5V supply rail via 1N4148 diode D3, allowing the unit to be powered by the connected computer for set-up and testing. D3 prevents current being fed back into the USB port if power is simultaneously applied to CON1.

The coil of DPDT relay RLY1 is driven by NPN transistor Q2 which in turn is driven by the micro's RC0 digital output (pin 10) via a 1kΩ current-limiting resistor. When pin 10 goes high, the relay is energised and the pairs of COM and NO terminals on CON3 are connected together.

When pin 10 is low, the relay is de-energised and the COM and NC terminals are connected instead.

When the relay is de-energised, the collapsing magnetic field in its coil causes a voltage to be induced across it and this is fed back into the 11.4V supply rail by diode D2, protecting Q2. LED4 is connected in parallel with the relay coil, along with a 10kΩ resistor and indicates when it is energised.

The trigger input at CON2 drives the base of NPN transistor Q1 via a 2:1 voltage divider comprising two 10kΩ resistors. The first 10kΩ resistor limits the base current of Q1 to a safe level while the second one acts as a pull-down, keeping it switched off if no voltage is applied at CON2.

Q1's collector is pulled up to the +5V rail via a 10kΩ resistor, so it operates as an inverter – when the voltage at the trigger input is above 1.6V, input pin RC2 (pin 8) of IC1 is pulled low and when the trigger input is below 1.0V, pin 8 is high. The software compensates for this inversion.

A 100nF capacitor from pin 8 to ground prevents any brief spikes or glitches at the trigger input from being detected as a trigger event. It has a time constant of around 1ms in combination with the 10kΩ pull-up resistor. A further trigger delay can be configured in the software, as described below.

The 10kΩ resistor from pin 6 (digital output RC4) to the trigger input at CON2 gives the option of pulling the trigger input high, to +5V when it is not driven. This allows you to connect a relay or switch across CON2 and when it closes, it will pull the input low.

If the input is being actively driven high/low then it will trigger the unit regardless of the state output pin 6 but setting it low will save a little bit of power. On the other hand, if you have a trigger source which actively pulls the input high but does not actively pull it low, you would need to switch

Features & specifications

- **Function: monostable or astable timer controlling a DPDT relay**
- **Timing period: on and off times programmable from 100ms to 50 days**
- **Timing adjustment: programmed over USB or using two trimpots (optional)**
- **Timing accuracy: typically ±0.25%**
- **Relay contact ratings: 30V DC/AC at up to 5A (8A with the Altronics relay)**
- **Trigger input: digital input (<1V low, >1.6V high) with pull-down or pull-up**
- **Trigger modes: trigger on high level, low level, rising edge, falling edge or state change with option to reset timer on re-trigger**
- **Power supply: 12-15V DC; 2mA with relay off, 45mA with relay on (or USB 5V for setup and testing)**
- **Indicator LEDs: four LEDs including power and relay state; two have adjustable time-outs**
- **Trigger delay: optional, can be set with 1ms resolution, min/max option**

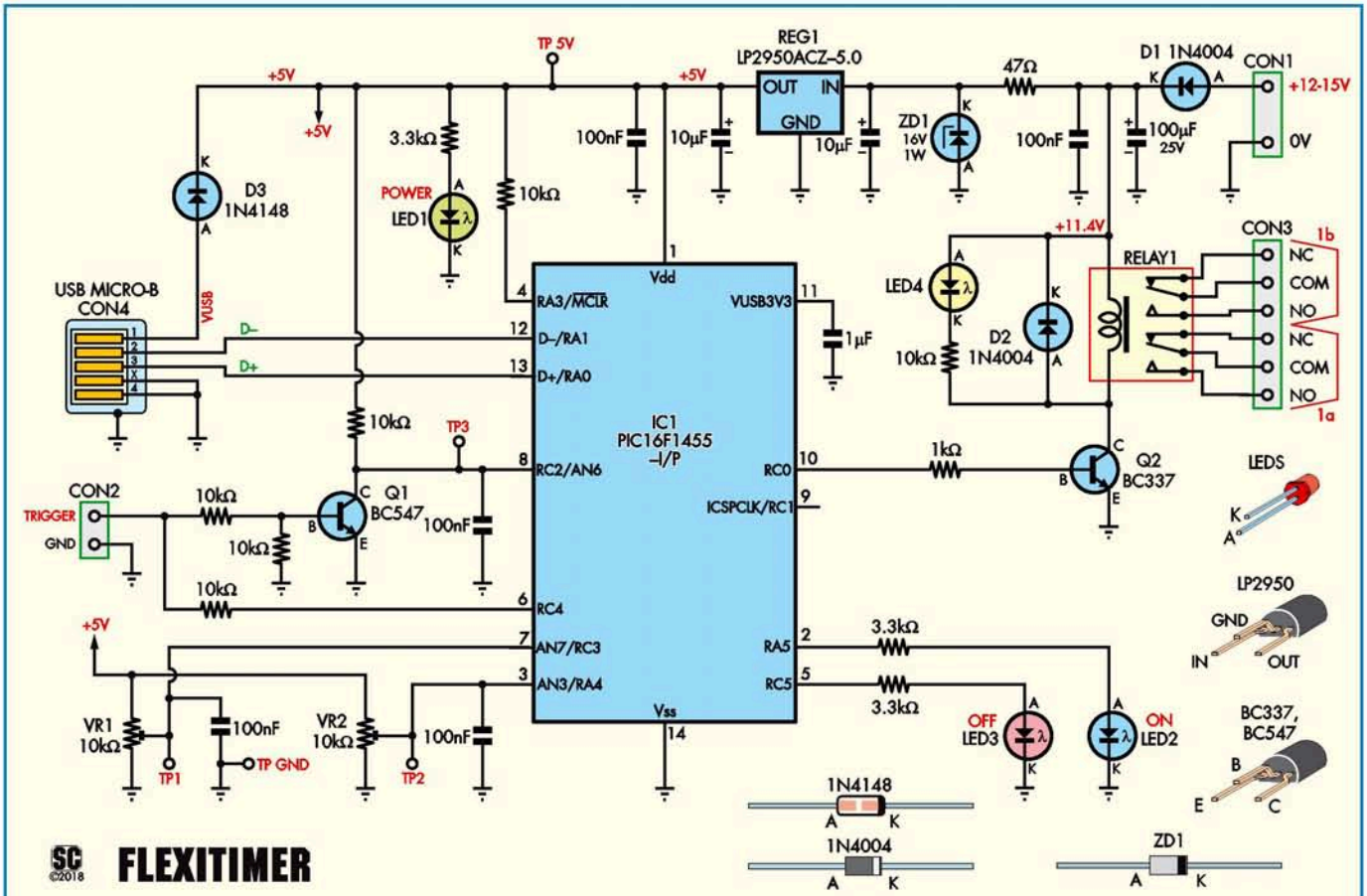


Fig.1: the heart of the USB Flexitimer is microcontroller IC1 and it is programmed by a computer connected using USB port CON4 or using trimpots VR1 and VR2. Transistor Q1 provides signal conditioning for the trigger input while transistor Q2 drives the coil of RLY1.

the pull-up off for it to work properly. That can be done via the USB interface.

Trimpots VR1 and VR2 are connected across the 5V supply rail so that their wipers sweep over a 0-5V range and they can be monitored at TP1 and TP2. These voltages are filtered by a 100nF capacitors (to keep the source impedance low, for maximum ADC accuracy) and then applied to analog inputs AN7/AN3 of IC1 (pins 7 and 3).

By default, trimpot VR1 adjusts the on time over a range of 1-60 seconds and VR2 the off time over a range from zero to 60 seconds.

You can use the USB interface to change this. You can set the minimum and maximum time for each trimpot and you can also set them to control different parameters such as the trigger delay, rather than the on and off times.

The various options will be described later.

The power supply is quite simple but designed to be rugged for vehicular use. The 12-15V DC supply is applied to CON1 and passes through reverse polarity protection diode D1. The resulting 11.4V (nominal) supply is filtered by a 100µF capacitor and fed directly to the coil of relay RLY1.

This supply rail is then further filtered by a 47Ω series resistor and 10µF capacitor and spikes are clamped by 16V zener diode ZD1. This filtered supply then feeds low quiescent current 5V regulator REG1 which supplies microcontroller IC1.

LED1, the power indicator, is connected across the 5V rail with a 3.3kΩ current limiting resistor, giving an operating current of around 1mA.

There is a 10µF filter capacitor on the 5V rail and a 100nF bypass capacitor close to IC1, while IC1 also has a 10kΩ pull-up resistor for its $\overline{\text{MCLR}}$ reset input so that it is reset at power-up and then operates continuously.

LEDs 2 & 3 are driven from outputs RA5 (pin 2) and RC5 (pin 5) of IC1, with 3.3kΩ current-limiting resistors, giving them a similar brightness to LED1 and LED4. These can be set up so that they are lit for a limited time period after the relay switches, to save power, as described below.

Basic operation

Fundamentally, the USB Flexitimer operates as follows. Initially, it waits for the trigger condition to be met, eg, for the trigger input to go high or low. There are five different trigger options as described in the options panel.

There is also an optional trigger delay. If enabled, the input must remain stable in this condition for that period to trigger the timer.

Once triggered, the relay is energised and the timer runs for the specified on time. The relay is then de-energised and the timer runs for the specified off time.

Once the off time expires, it will go back into the initial state, waiting for a trigger event at the input.

By default, with nothing connected to CON2, the timer will run continuously, switching the relay on and off in a pattern. This is because (also by default) pin6 is held high and the trigger condition is a high level at CON2.

Thus the timer is automatically triggered at the start of the process.

Note that the relay is not energised

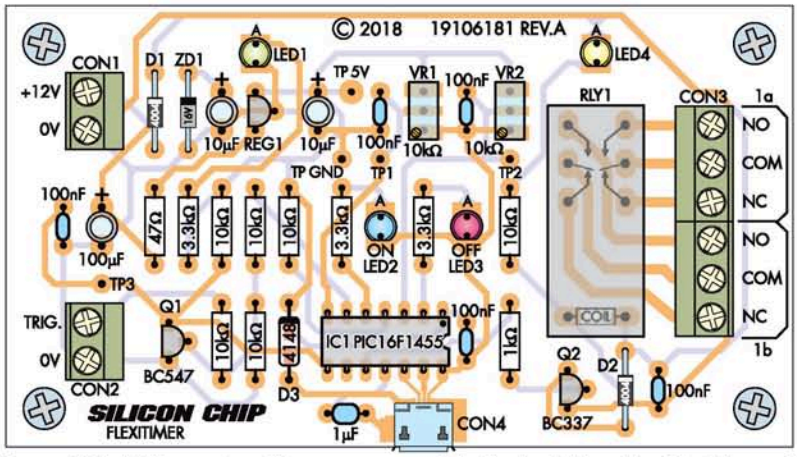


Fig.2: use this PCB overlay diagram as a guide for building the Flexitimer. The USB socket CON4 is the only surface-mounting device. IC1, D1-D4, VR1, VR2 and the electrolytic capacitors are polarised and must be installed as shown here. It can be fitted into a USB plastic Jiffy box or mounted in any other suitably sized enclosure.

during the off time and for the trigger delay time, so if you need a precise off-time and have a trigger delay time, you should subtract the delay time from the off time that you set.

Construction

The USB Flexitimer is built on a double-sided PCB coded 19106181 and measuring 104 x 58.5mm. This can be installed in a standard UB3 Jiffy box or any other enclosure with suitable internal dimensions.

Use the PCB overlay diagram, Fig.2, and photo as a guide while fitting the components.

Pre-programmed microcontrollers are available from the SILICON CHIP Online Shop or you can program one yourself, if you have a suitable programming device, using the HEX file downloaded from www.siliconchip.com.au

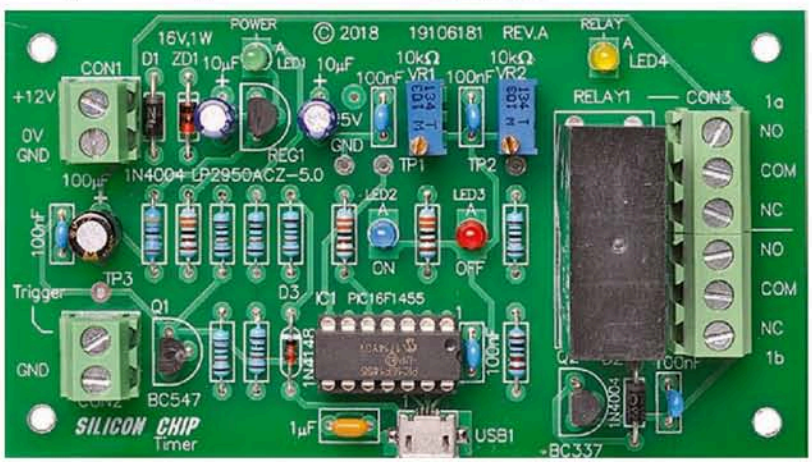
Start by mounting the micro USB socket. Apply some flux paste to the five small pads and the two larger mounting pads. Place the part on the board, ensuring the two small plastic posts go into the corresponding holes in the PCB.

Check that the five small signal pins line up with their matching pads and then solder one of the side mounting tabs to the board.

Now re-check the alignment of the signal pins. If it's off, re-melt that solder joint and nudge the part into it's correct position. Then solder the five signal pins.

It's very difficult to avoid bridging them, so it's easier to simply make sure all of them are soldered to the pads on the board and then apply some extra flux paste and use a piece of solder wick to remove the excess solder.

Next, solder the second mounting tab so that the socket is held rigidly into place.



This same-size photograph of the assembled PCB, in conjunction with the component overlay above, shows where each of the components goes.

Parts list – USB Flexitimer

1 double-sided PCB, 104 x 58.5mm, coded 19106181
1 DPDT 12V DC coil relay (RLY1) [Jaycar SY-4052 (5A), Altronics S 4270A (8A)]
2 2-way terminal blocks, 5.08mm pin spacing (CON1,CON2)
2 3-way terminal blocks, 5.08mm pin spacing (CON3)
1 SMD micro USB socket (CON4)
1 14-pin DIL socket (optional, for IC1)
1 UB3 Jiffy box (optional)
4 short M3 tapped spacers and 8 short M3 machine screws (optional, for mounting in box)
2 cable glands (optional, for wiring when mounted in box)

Semiconductors

1 PIC16F1455-I/P microcontroller programmed with 1910618A.hex (IC1)
1 LP2950ACZ-5.0 micropower linear 5V regulator (REG1)
1 BC547 NPN transistor (Q1)
1 BC337 NPN transistor (Q2)
1 3mm green high-brightness LED (LED1)
1 3mm blue LED (LED2)
1 3mm red high-brightness LED (LED3)
1 3mm yellow high-brightness LED (LED4)
1 16V 1W zener diode (ZD1)
2 1N4004 1A diodes (D1,D2)
1 1N4148 small signal diode (D3)

Capacitors

1 100µF 25V PC electrolytic
2 10µF 16V PC electrolytic
1 1µF 50V multi-layer ceramic or 63/100V MKT
5 100nF 63/100V MKT

Resistors (all 0.25W, 1% metal film)

6 10kΩ 3 3.3kΩ 1 1kΩ 1 47Ω
2 10kΩ 25-turn vertical trimpots (VR1,VR2)

You can then move on to the resistors. It's best to check their values with a DMM before soldering them in place. Follow with the diodes.

There are three different types so don't get them mixed up and make sure the cathode stripes are orientated as shown in Fig.2.

If using an IC socket, solder it in place now, ensuring that its notched end is orientated correctly. Otherwise,

mount IC1 directly to the board with the same orientation.

Then install the 100nF and 1µF capacitors, followed by transistors Q1 and Q2 and regulator REG1. The small capacitors are not polarised.

You may need to bend the leads of the transistors out slightly to fit the PCB pad locations before fitting them. Don't get the transistors and regulators mixed up as they are in similar packages.

Next, fit terminal blocks CON1-CON3. CON3 consists of two 3-way terminal blocks which are dovetailed together before soldering. In each case, make sure that the wire entry holes face the nearest edge of the PCB.

If you are installing the optional trimpots (VR1 & VR2), do it now. Make sure you insert them into the PCB with the adjustment screw orientated as shown in Fig.2.

Now fit the electrolytic capacitors, ensuring that their longer lead (+) goes into the pads marked positive on the PCB. The striped side of the can indicates the negative lead.

You have the option of mounting LEDs1-4 right down on the PCB, as we have done on our prototype, or mounting them on longer leads so that they will protrude through the lid of the case.

Alternatively, you can chassis-mount some or all of them and wire them to the board with flying leads.

You can leave LED1 and/or LED4 off if you need to minimise current consumption.

Regardless of how you mount the LEDs, make sure that their longer (anode) leads connect to the pads marked "A" on the PCB.

Now push the relay down fully onto the PCB in the location provided and solder its pins.

Finally, if you have fitted an IC socket for IC1, straighten its pins and insert it into the socket now, taking care that you don't fold any of the leads under the package when doing so.

Testing

The easiest way to test the completed board is to plug it into a USB port on your computer using a standard type A to micro type B cable.

LED1 should light up immediately and your computer should identify a new USB device. Most operating systems (including Windows 10) should not need a driver as it appears as a standard serial device.

Note that the USB cable powers the PCB at this point. There is no need to connect a DC power supply. That step comes later.

In Windows 10, you can verify that it is working by opening Device Manager and expanding the "Ports (COM & LPT)" section. It should appear as

Software details

You might think that the software for a timer would be simple. But due to the USB interface and the flexibility of this design, we were barely able to squeeze the required functions into the 14KB (8K words) of flash memory available.

The firmware is written in the C language rather than assembly language for two reasons: one, it would have taken a lot longer to write in assembly language and two, the Microchip USB sample code is in C. It is converted to a HEX file using the Microchip XC8 compiler. The free version lacks full optimisations so you can't use it to compile this code as the result will not fit in the available flash memory.

The source code can be downloaded from the SILICON CHIP website if you are interested in how it works.

To start with, we took the Microchip CDC (USB serial) sample program and stripped out all the parts we didn't need. This resulted in a program that simply echoed back what you type into the terminal and that code already took up around 30% of the available flash memory.

Given the number of "strings" (ie, sequences of characters) required for the command line interface in this project, we quickly realised that we would have to devise a custom method of storing these strings in flash.

That's because the default behaviour of the XC8 compiler is to store each character in one flash word (14 bits). So the ~1000 characters we ended up needing would take up 1K words, or 12.5% of the available flash.

But since we're not using accented characters, just basic ASCII, all our characters have codes in the range of 0-127. That means they will fit in 7 bits and hence, each 14-bit flash word could be used to store two characters, not one.

So we wrote a little program that took a list of strings and packed it into 14-bit program words, then produced an ASM file to link in with the C file. We also needed two new routines, one to unpack the words and write the strings into a memory buffer (identified by their offset in the "blob") and another to compare the packed words to the contents of a memory buffer, for parsing commands typed by the user.

Overall, this freed up about 5% of the flash memory for extra code. And the program takes up over 99% of the flash so we certainly needed that breathing room.

We also wrote our own functions to convert numbers to and from ASCII strings, also for the command line interface, as they turned out to be smaller than the equivalent C library functions (although we do make use of the "strtoul" built-in function, to convert a string to a 32-bit integer).

Timing is based on the micro's internal oscillator which runs at 12MHz and uses "active clock tuning", to lock it to the USB host's clock so that it meets USB timing specifications.

This is used to increment a 16-bit variable in memory at 1ms intervals using the internal TIMER1 hardware with a pre-scaler value of 16 and pre-loading the TMR1 register with the value 64786, which causes the timer 1 roll-over interrupt to trigger 750 intervals later. 750 x 16 = 12,000, giving us our 1ms interval relative to the 12MHz system clock.

This millisecond counter variable is then used by the logic in the main loop of the software to determine how long to wait and when to change the relay state based on the trigger input logic level. It also makes use of the configuration data, which is copied from the high-endurance area of flash memory to RAM at start-up.

Much of the time spent developing this software consisted of finding ways to re-write code to take up less flash space. Many of these optimisations involved moving commonly used code sequences into functions to avoid them having to be stored in multiple locations in flash. But this didn't always help since function call overhead on the PIC16 is fairly high.

In fact, we found the results of the XC8 compiler to be somewhat unpredictable; one seemingly inconsequential change could result in a 15% increase or decrease in flash memory utilisation! So a lot of experimentation was required to find the best combination of code to achieve the desired result.

Configuration options

There are six settings that control the operation of the timer. They are: the trigger condition, four timing values (with some extra options) and whether the input pull-up resistor is enabled. Each is explained below. The four timing values are: the on time, the off time, the trigger delay time and the indicator LED on-time.

When reading the following explanation, keep in mind that the relay is energised while the main (on) timer is running and de-energised the rest of the time.

Trigger conditions

There are five possible input trigger conditions which will start the timer. These are when the input is a high level, low level, on a rising edge, on a falling edge or on either edge (input state change).

The high level and rising edge settings operate in a very similar manner, as do the low level and falling edge settings. The difference is what happens after the timer has elapsed. If you have the input trigger condition set to high level and the input is still high after the timer has elapsed, it will start again.

But if you have it set to rising edge, it will not. The input will have to go low and then high again to re-start the timer. It doesn't matter whether it goes low during the on time and then high later, or low after the timer has expired and then high again; what matters is the low-to-high transition must occur after the timing period has expired.

Similarly, in the input state change mode, the transition must occur after the timing period has finished to start a new one.

Having said all that, there is a separate option to reset the timer if a trigger condition occurs during the timing period. If this is enabled and the trigger conditions are met during the timer period, it will start over. That option is explained below.

The on time

This controls how long the relay is energised. While the resolution is 1ms, the minimum practical value is around 100ms, given that the relay will take around 10ms to switch on and off. The maximum time is 1193 hours which works out to almost 50 days.

Like the other time options, the on-time is set using a string which looks like one of the following: "1h15m23.572s" or "1500ms" or "75m".

If you specify an exact on time then each time the unit is triggered, the relay will be on for exactly that period. However, you can also specify it as a minimum or maximum on time.

If specified as a maximum, the timer will be cancelled and the relay de-energised if the input changes state before the timer has expired. So the timing period will range from a few milliseconds up to the period specified.

Conversely, if specified as a minimum, the relay will be energised for the time period specified and then, if the input has not changed state during that period, it will remain energised until the input does change state. So the timing period ranges from the time specified up to the length of the input trigger pulse.

Finally, there is the option to make the on time "resettable". This means that if the input trigger condition is met during the on time (including any delay, as described below), the timer starts again from zero. So if the input is repeatedly triggered, the on time will be extended each time. This does not make sense to specify with a maximum on time but it can be used in combination with an exact or minimum on time.

Off time

As soon as the timer expires or is cancelled, the relay is de-energised. You can set the off time to zero, in which case, as soon as the trigger conditions are met again, the timer will start again from zero and the relay will be re-energised.

However, if you specify a non-zero off time, then another timer is started and nothing will happen until it expires. You can use this to enforce a minimum time between the relay being de-energised and then re-energised.

It's also useful in a situation where you want the relay to be switched on and off at a particular interval or cadence. In this case, you can set the on time and the off time and arrange for the trigger condition to always be true. The relay will then continually switch on and off at the specified intervals.

As with the on time, the off time can range from 1ms up to nearly 50 days but again, the minimum practical off time is around 100ms.

Trigger delay time

If the trigger delay time is set to zero then the timer will start and the relay will be energised as soon as the trigger conditions are met (either immediately after power-on or after the off time has elapsed).

However, you can specify a non-zero trigger delay time, in which case the input level will need to be stable for this period before the timer will actually start, and the relay will remain de-energised during this time. You can also use this as a way to purposefully insert a delay between the trigger signal and the relay being energised.

The range of the trigger delay time is the same as the other times, however, it would generally be a shorter period, from a few milliseconds to a few seconds.

It's also possible to have a fixed trigger delay period, which simply means that it doesn't matter what the trigger input does during the delay period; as long as it initially met the trigger conditions, after the fixed delay, the relay will be energised. This would be useful, for example, if you want to trigger the timer with the push of a momentary pushbutton but have a delay between that button press and the relay switching.

There's also a third option for the trigger delay and that is to specify it as a maximum time. In this case, once the trigger condition has been met, the unit waits for the input to change state and if the period of this trigger pulse is less than or equal to the specified maximum, the on timer starts and the relay is energised. Otherwise, the trigger pulse is ignored.

For example, if you were using a photo interrupter to trigger the unit, this would allow you to set it up to be triggered by fast-moving objects but not slow-moving ones.

LED on time

By default, LED2 lights while ever RLY1 is energised and LED3 lights while ever RLY1 is de-energised. However, you can specify a finite LED on time. In this case, LED2 lights as soon as RLY1 is energised and then switches off after the LED on time has elapsed. Similarly, LED3 lights as soon as RLY1 is de-energised, for the same time period.

If running the USB Flexitimer off a battery, you may want to minimise its power consumption, in which case you could set the LED on time to be quite short and leave LED1 off entirely. In this case, its standby current will be around 1mA without VR1 and VR2, or 2mA if they are fitted.

Changing the configuration via USB

With the unit plugged into your computer and the terminal emulator connected as per the testing instructions, you can issue the following commands (shown here in red) to change the unit's configuration. Note that the changes will not be retained after power is switched off unless you issue a "save" command. Also, you need to press Enter/Return after typing a command and check that you get a positive response.

pull-up (on|off)

Sets whether the input pull-up resistor is driven or not. For example:

```
pull-up on
Done.
```

set trigger on (high|low|rising|falling|change)

Issue this command to set the trigger condition to one of the five possibilities listed. For example:

```
set trigger on rising
Done.
```

set on time [min|max] [resettable] <time>

Sets the on time to a fixed value. The "min", "max" and "resettable" keywords are optional and must be provided in that order (if using both). The time is specified as stated earlier, for example:

```
set on time min resettable
1h15m10.5s
Done.
```

set on time [min|max] [resettable] VR(1|2) <time> to <time>

Sets the on time to a variable value controlled by either VR1 or VR2, over the specified range. For example:

```
set on time max VR1 1m to 1h
Done.
```

set off time <time>

Sets the off time to a fixed value. For example:

```
set off time 30s
Done.
```

set off time VR(1|2) <time> to <time>

Sets the off time to a variable value controlled by either VR1 or VR2, over the specified range. For example:

```
set off time VR2 100ms to 1500ms
Done.
```

set trigger delay [min|max|fixed] <time>

Sets the trigger delay to a fixed value. If you don't specify "min", "max" or "fixed", the default is "min". For example:

```
set trigger delay 25ms
Done.
```

set trigger delay [min|max|fixed] VR(1|2) <time> to <time>

Sets the trigger delay to a variable value controlled by either VR1 or VR2, over the specified range. For example:

```
set trigger delay fixed VR1
10ms to 100ms
Done.
```

set led timer <time>

Sets how long LED2/LED3 stay on once the relay state changes. Instead of a time value, you can specify "infinite" so that they are continuously lit. For example:

```
set led timer 30s
Done.
```

set led timer VR(1|2) <time> to <time>

Sets the on time for LED2/LED3 to a variable value controlled by either VR1 or VR2, over the specified range. For example:

```
set led timer VR2 1s to 10s
Done.
```

show [active] config

Shows the unit's current configuration, ie, that which it is actively using to control the relay. Includes any changes you have made since power was applied, even if they haven't been saved yet. For example:

```
show config
```

On when input is high for at least 50ms (pull-up on).
Stays on for 1s to 1m (VR1).
Off for: 0ms to 1m (VR2).
LED timer: infinite.

show status

Displays the current input state, whether the relay is energised, the current timer value, the positions of the trimpots and the corresponding time values. Can be helpful as a debugging aid if the unit is not doing what you expect. For example:

```
show status
```

Input: high.
Relay: energised.
State: relay on for 31.226s/1m.
VR1 controls relay on-time (now 100% = 1m).
VR2 controls off-time (now 51% = 30.600s).

show saved config

Shows the unit's stored configuration, ie, that which is loaded at power-up. Does not include any unsaved changes you have made.

save

Saves any changes made to the configuration into the EEPROM. They will, therefore, be applied each time the unit is powered up.

revert

Discards any changes made to the configuration and loads the previous configuration from the EEPROM. Has the same effect as power cycling the device without saving the changes.

help

Displays a short list of these commands.

Resistor Colour Codes

	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	6	10kΩ	brown black orange brown	brown black black red brown
❑	3	3.3kΩ	orange orange red brown	orange orange black brown brown
❑	1	1kΩ	brown black red brown	brown black black brown brown
❑	1	47Ω	yellow violet black brown	yellow violet black gold brown

"USB Serial Port (COMx)", where x is a number.

Next, open a terminal program like Tera Term Pro and set it to use that serial port (in the Setup → Serial Port menu). The baud rate and other settings do not matter. Then return to the terminal emulator and type "help" and then press Enter/Return.

You should see the help command echoed back to you as you type and a list of commands should then be displayed when you press Enter/Return. This verifies that the USB interface and microcontroller are working.

The default configuration results in the unit being self-triggered because the input pull-up resistor is active and the trigger condition is on a high input.

As a result, you should see LED4 flashing at a rate determined by the positions of VR1 and VR2 (or at random intervals if those potentiometers have not been fitted). You should also see LED2 and LED3 switching on and off at the same time as LED4 changes state.

If you have fitted VR1 and VR2, adjust them and check that the on time and off time of LED4 vary as expected.

Otherwise, you can issue commands such as "set on time 1s" and "set off time 1s" to change the on and off time and check that they vary as expected.

If you short the terminals of CON2 then LED4 should stay off once it switches off as the unit is no longer being triggered.

At this point, you could hook up a 12-15V DC supply to CON1 and check that the relay clicks on and off at the same time that LED4 lights up or goes dark.

Setting it up

Now that you have it connected to your PC, this is a good opportunity to set up the configuration to your requirements.

See the panel opposite on changing the configuration for the list of commands that you can use to set it up. It's a good idea to start by issuing the "show config" command to see the current (default) settings. Don't forget to use the "save" command when you have finished.

You'll probably want to read through the panel on timing options first, to understand how the unit works, so that you can figure out how best to set it up for your particular application.

If you're setting it up to activate with an external trigger, you can simulate this by shorting the trigger pin on CON2 to either +12V or GND, to pull the input high or low.

The default configuration is as follows. The input trigger condition is on a high level with a 50ms (minimum) trigger delay.

VR1 varies the on time over the range of 1-60s, which is set in exact mode (not minimum or maximum). VR2 controls the off time over the range of 0-60s. LED3 and LED4 are constantly illuminated. The pull-up resistor is enabled and timer resetting by the trigger input is disabled.

If you're having trouble getting the timer to operate in the intended manner, you can plug it into the USB port of a computer and use the "show status" command to see what it is doing.

The result includes information on whether the device has been triggered, which timer is currently in operation, how long it has been running for and when the next state change will occur.

Housing it

The PCB is designed to fit inside a UB3 Jiffy box (130 x 67 x 44mm). It has a mounting hole in each corner so that it can be attached to the base of the box using M3 tapped spacers and short machine screws.

Alternatively, you can mount it inside some other piece of equipment, possibly that which it is switching on and off.

If you do decide to mount it in a UB3 Jiffy box, you could fit cable glands at either end for power wires and for the wires which connect to the relay contacts.

If you want to be able to re-program it while inside the box, you will also need to make a rectangular cut-out in the side to access the USB socket. SC

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WOW! That's what we'd call an LC METER you really should build!

By Tim Blythman

Not only is this new digital Inductance-Capacitance Meter easy to build (it's based on a custom Arduino shield and a standard 4-line alphanumeric LCD display), it features very low drift due to a constant self-calibration procedure. Best of all, it has an extended measurement range from less than 1pF to over 1F (yes, 1 FARAD!!) for capacitors and under 100nH to several henries for inductors. You simply must add this one to your test equipment arsenal!

A **wide range LC Meter** is a very worthwhile device to have on your workbench. But have you tried to buy a good one lately? (Hint – mortgage the kids first!).

Many DMMs have a capacitance meter built in but their range is usually (very!) limited. And most cannot measure inductance at all.

But now you can have an ultra-wide range LC meter which has all the "most wanted" features – high accuracy, very low drift . . . and best of all, it won't cost you a lot to build.

That's mainly because it is based on an Arduino processor. You can choose to build it in a case as a genuine piece of test gear . . . or assemble it with your Arduino Uno whenever you need to measure a capacitor or inductor.

This design is very accurate because it automatically compensates for its own thermal drift and it can measure very small and very large capacitance and inductance values.

It automatically senses the component type, so you can connect virtually any capacitor or inductor, big or small, to the device and it will quickly tell you its value on the LCD screen. You can even measure supercapacitors!

This is actually the third LC Meter that we have published in the last twelve months. This latest iteration is a big improvement over the last two, both in both performance and ease-of-use while being only slightly more complex.

Most importantly, it solves the drift problem that has plagued most DIY LC Meter designs and many commercial designs as well.

Why "measurement drift" is a problem

This type of LC Meter design has a long history. Our projects in May 2008, June 2017 and January 2018 were all based on an earlier design by Neil Heckt from around 1998, which used a PIC16C622 microcontroller.

These are all based on an oscillator which incorporates the unknown device (inductor or capacitor) to be measured.

The parameters of the device to be measured (eg, inductance or capacitance) affect the oscillator frequency and by measuring the change in frequency, we can estimate its inductance or capacitance.

This approach requires us to measure the initial oscillator frequency, then the frequency with the unknown device in circuit and then calculate the difference. A formula is then used to compute the inductance or capacitance.

The problem is that all those previous designs only measure the initial (default) oscillator frequency when the unit is first powered up. That's because the user has to manually disconnect any components from the test terminals. Unfortunately, as the unit warms up, the oscillator frequency shifts.

So unless you disconnect the device under test (DUT) and "reboot" the Meter every time you want to make a new measurement, it won't necessarily be accurate.

That inevitable drift in oscillator frequency means that regardless of how precise the initial calibration may be, each successive measurement is likely to be progressively less accurate.

Our solution is simple: get the microcontroller to frequently disconnect and re-connect the DUT from the circuit. So it can measure the oscillator frequency with and without the DUT (device under test) at very short time intervals and compute the difference on this basis.

So it's constantly compensating for any drift due to temperature, ageing or other factors.

The microcontroller uses reed relays to switch the DUT in and out of circuit. You don't have to do anything to select or control this process; the microcontroller does it automatically.

At the same time, the micro can decide to add some extra components which allow it to make measurements using a different method that's more suitable for higher values of capacitance and inductance.

This is how we've greatly extended its measurement range.

We have not made any changes to the oscillator circuit around IC1, compared to our last LC Meter (January 2018; siliconchip.com.au/Article/10934).

We spent some time looking for ways to improve this but there doesn't appear to be any easy way to improve it.

If you want more details on how the oscillator is used to measure the inductor or capacitor value, see Jim Rowe's detailed description in the June 2017 issue at: siliconchip.com.au/Article/10676

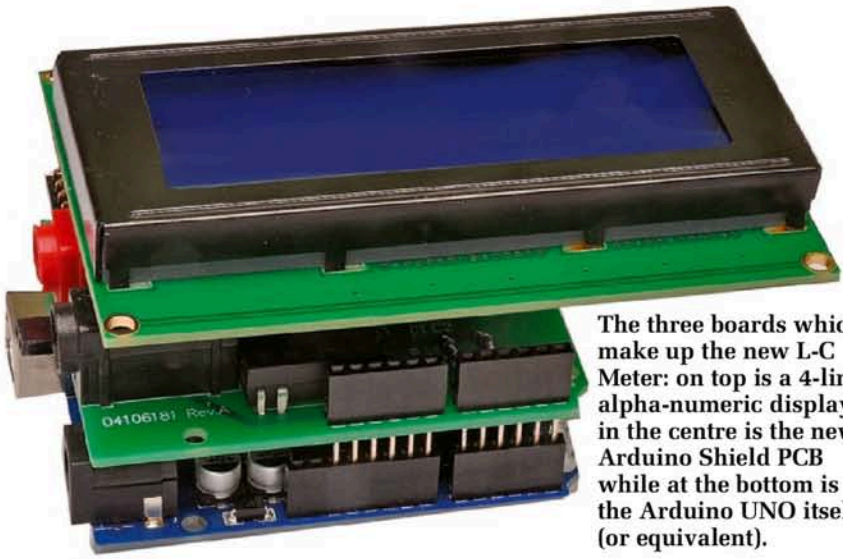
Extending the measurement range

Our previous designs and indeed any LC Meters based on this circuit configuration are limited to handling a maximum capacitance value of slightly more than 1µF and a maximum inductance of around 100mH. Values

Features & specifications

Advanced calibration
Continuous drift compensation
Long-term averaging
Inductance range: 10nH to 1H+
Capacitance range: 0.1pF to 1F+ (minimum rating 5V)
Measurement resolution: four significant figures
Component detection: automatic
Sampling rate: Once every two seconds (approx)
Accuracy (when calibrated): within ±1% of reading
Supply voltage: 5-12V DC @ <100mA
Easy-to-assemble, low cost Acrylic case available.

If you're a typical hobbyist – or even a repair centre – you've probably got a pile of capacitors in your junk box and don't know if they're good, bad or indifferent. And even your DMM can't tell you because it won't go high enough, especially for electros. Build this LC meter and you can check them all (even supercaps) – plus all those inductors with no markings!



The three boards which make up the new L-C Meter: on top is a 4-line alpha-numeric display; in the centre is the new Arduino Shield PCB while at the bottom is the Arduino UNO itself (or equivalent).

higher than this tend to prevent the oscillator from functioning.

Since there is no easy way to fix the oscillator to solve this range problem, we've used a different method to measure large component values, based on measuring the time constant of an RC or RL circuit.

A separate panel in this article explains how that method works.

To allow for this extra measurement mode, we needed a way to disconnect the DUT from the oscillator but luckily, we had already added that capability using reed relays for the drift cancellation feature.

We also needed a way to disconnect the time constant measurement circuitry from the DUT so that it doesn't affect the oscillator – but that turned out to be easy.

The pins on the micro which perform the new measurement function are simply set into a high-impedance state when not being used and they then have virtually no effect on the behaviour of the oscillator.

In the end, the only changes required to add this new measurement mode were two resistors and some extra software routines.

Aaaagh – I just built the earlier LC Meter!

Stay calm and don't panic! You haven't wasted your money . . . We thought about those readers who have a previous version of an LC Meter and made it easy (and cheap!) for you to upgrade.

Just transfer most of the existing components from your previous shield board to our new custom shield, install the four new reed relays and extra resistors, port in the new software and it's done.

Or you you can simply install fresh components on the new shield and go from there.

Circuit description

The full circuit diagram is shown in Fig.1. Everything except the Arduino and 20x4 alphanumeric LCD is mounted on the shield board for the Arduino.

Let's look first at how the oscillator-based measurements are made.

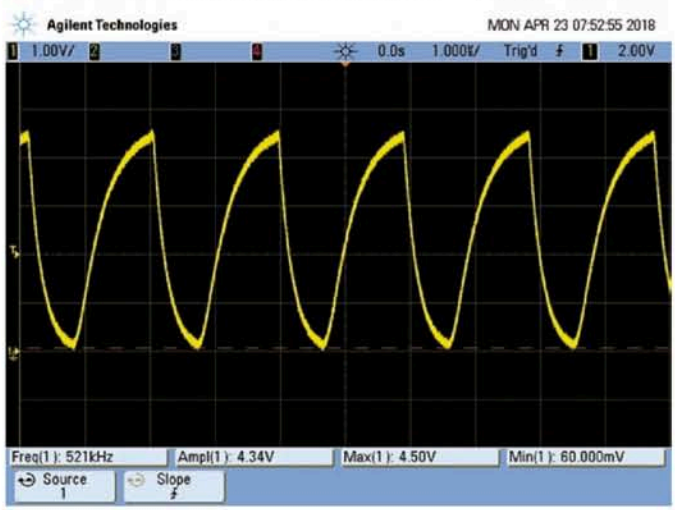
IC1 is a high-speed LM311 comparator, used to drive the resonant circuit into oscillation. The resonant circuit consists of inductor L1 (100µH) and capacitor C1 (1nF). The junction of these two components is coupled to the non-inverting input of IC1, pin 2, via a 10µF capacitor.

Positive feedback is provided around IC1 by a 100kΩ resistor from its pin 7 output to the pin 2 non-inverting input. Pin 2 is also connected to a divider across the 5V rail so that when pin 7 of IC1 goes high, the voltage at pin 2 will be pulled up to around 2/3 of the 5V supply, or 3.3V.

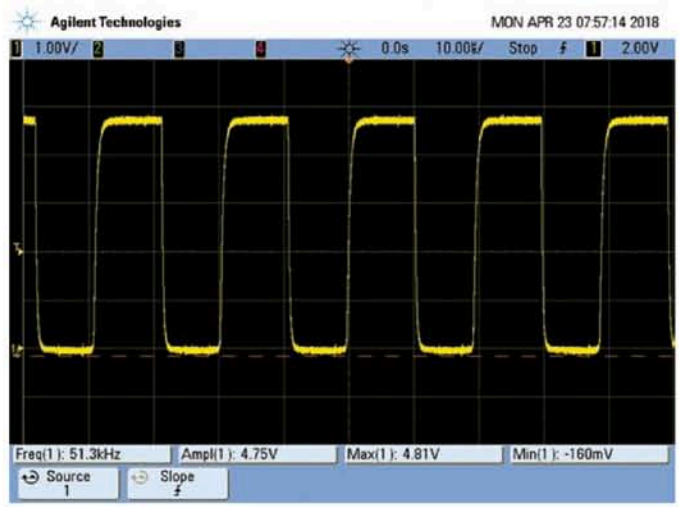
Since IC1's output is a transistor collector, a 4.7kΩ pull-up resistor is used to take it to 5V when that transistor switches off and it goes low, to 0V, when the transistor switches on.

The pin 3 inverting input of IC1 is connected to the output via an RC low-pass filter (47kΩ/10µF) and the capacitor charges up to the average output voltage so that the oscillator should stabilise with a reasonably symmetrical waveform.

This waveform is fed to digital input pin D5 of the Arduino via a 6.8kΩ current-limiting resistor.



Scope1: measurement of the F1 frequency during the calibration phase. As detected by the scope, the frequency is 521kHz with an amplitude of 4.34V.



Scope2: measurement of a 100nF capacitor. The frequency has dropped to 51.5kHz. Note the amplitude is up to 4.75V, and the oscillator seems quite stable.

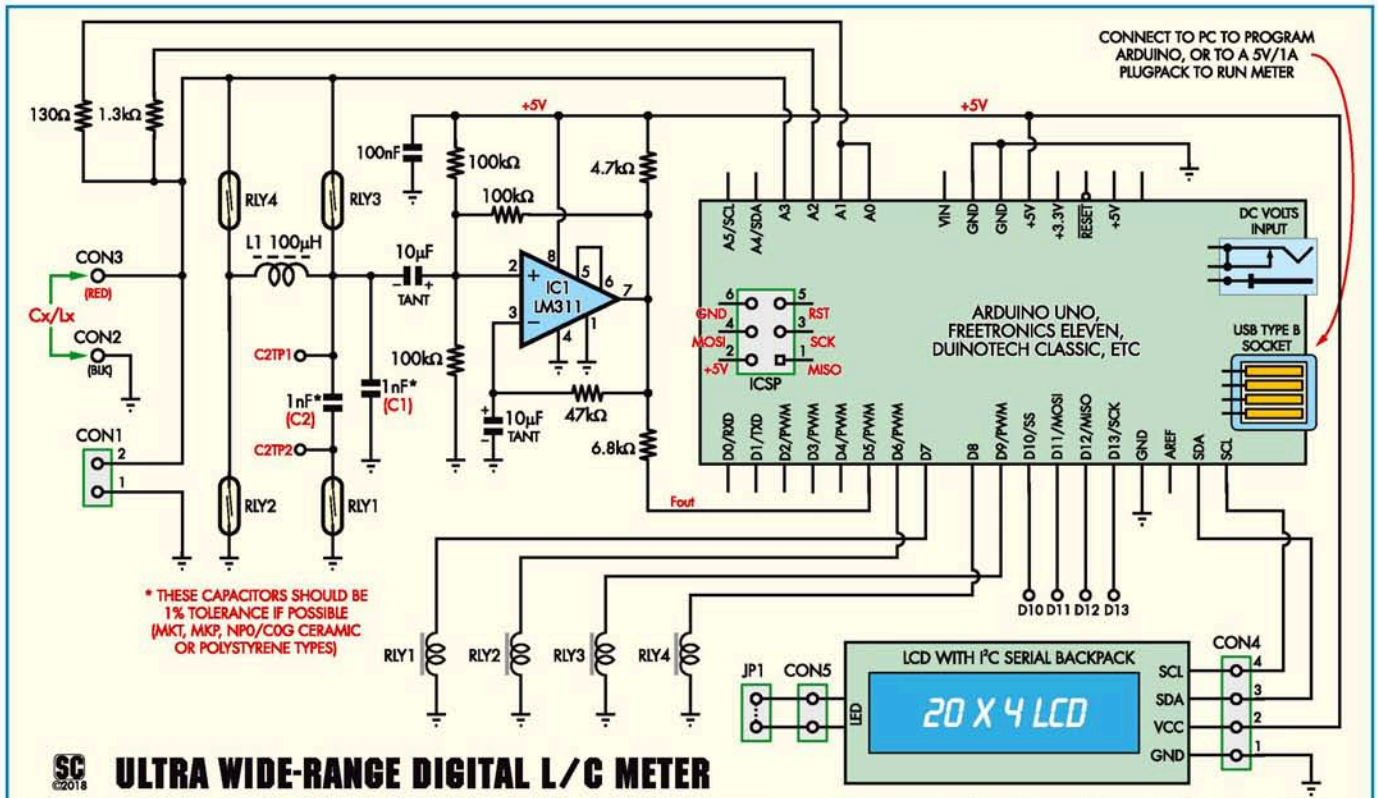


Fig.1: complete circuit of the new Arduino LC Meter. The component to be measured is plugged into CON1 or CON2/CON3 which is then connected to the test oscillator by RLY3 or RLY4, depending on its type. The Arduino can also perform time-constant based value measurements using its A0-A3 pins and the 130Ω and 1.3kΩ resistors.

Oscillator configurations

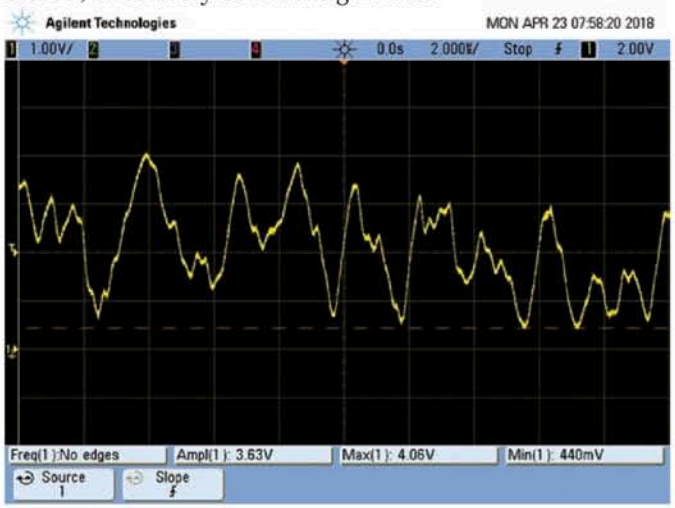
Four reed relays, RLY1-4, each connect either to one end of L1 or to the calibration capacitor C2 and are used by the micro to select one of five different modes.

The state of each relay in each mode is shown in Table.1. Each mode works as follows.

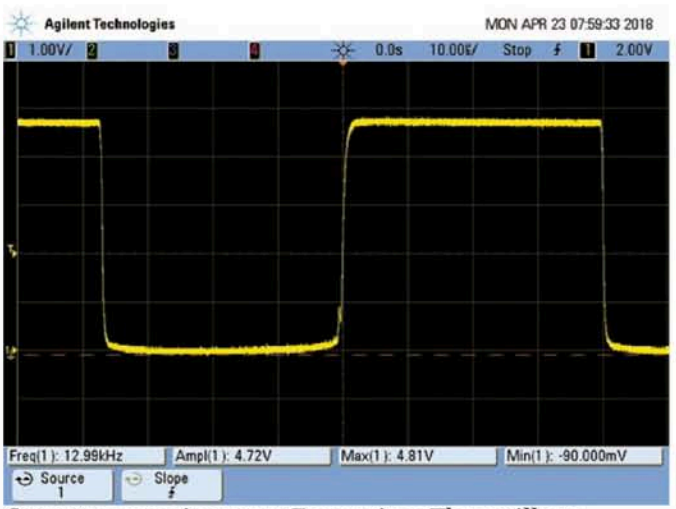
Mode 1 is for oscillator calibration. RLY2 is energised and its contacts are closed, effectively connecting L1 and C1 in parallel. The other relays are not energised. L1 and C1 resonate and cause IC1's output to produce a square wave of around 500kHz, which can be measured by the Arduino using its internal timer hardware.

Mode 2 is also for calibration. Both RLY1 and RLY2 are now energised but RLY3 and RLY4 are not. This is identical to the first mode except that now, C2 is connected in parallel to C1. The oscillator frequency drops to around 370kHz, due to the doubled capacitance. This allows the unit to measure the stray capacitance on the PCB and provide more accurate component value measurements.

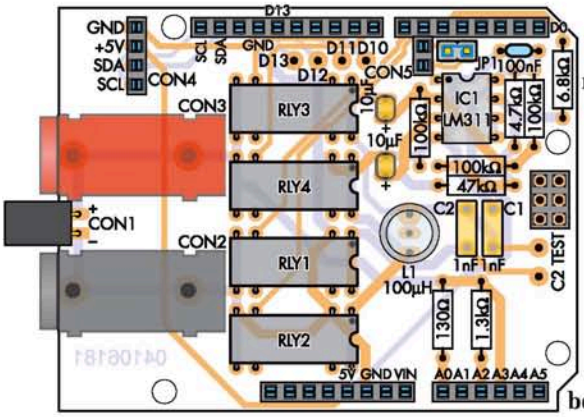
Mode 3 is for measuring the value of a capacitor connected either between the pins of CON1 or between banana sockets CON2 and CON3 (these are effectively in parallel). In this case, RLY2 and RLY3 are energised and RLY1 and RLY4 are not. This is similar to the first



Scope3: in this case the oscillator is not stable when measuring a 407µF capacitor. To get an accurate measurement you need to use the RC method (see Scope6).



Scope4: measuring a 1.5µF capacitor. The oscillator appears stable, but a small glitch appears at the start of the leading edge.



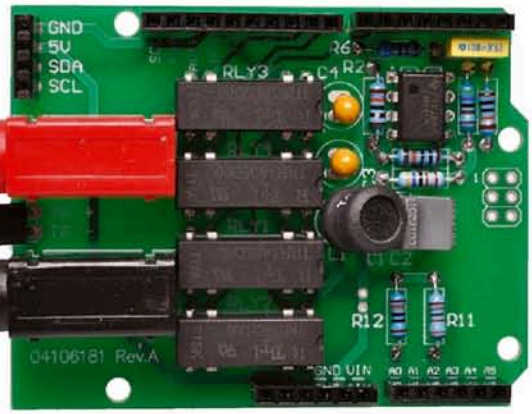


Fig.2: follow this overlay diagram – and the photo at right – to build the LC Meter shield PCB. Be careful with the placement of L1 as an extra pad is provided for larger inductors; also ensure that RLY1-RLY4, IC1 and the two tantalum capacitors are fitted with the orientation shown. The PCB at right is an early prototype; some minor adjustments have been made in the final version.

mode except that now the DUT is connected in parallel with C1.

Since the capacitance has increased, this should result in a lower oscillator frequency and by measuring the change, we can calculate the capacitor value, using the method explained previously.

Mode 4 is for measuring inductance. In this case, only RLY4 is energised. The DUT is connected in series with L1 and its opposite end is connected to ground via CON1 or CON2.

This means that the resonant circuit inductance has effectively increased (by the value of the DUT) and so once again, the oscillator frequency should drop and the difference can be used to calculate the inductance of the unknown component.

As explained earlier, in the above modes, the A0-A3 pins on the Arduino are kept in a high impedance state so they won't interfere with the oscillator. Their only influence is in their (small) pin capacitance and this is compensated for during calibration.

Mode 5 is used for measuring high values of inductance and capacitance, and now the A0-A3 pins become active.

In this mode, all four relays are off and the DUT is not connected to the oscillator. Instead, the 130Ω and 1.3kΩ resistors are used to drive the DUT and A0, A1 and A2 become outputs at different times.

A0 and A1 are connected together to measure the internal pin resistance, as this appears in series with the 130Ω resistor and can cause measurement errors.

The A3 pin is used as an analog input, to measure how the voltage across the DUT changes in response to the current from the other two pins.

The two different resistors value are used to provide two different ranges, to improve the unit's accuracy. In this mode, capacitance and inductance measurements are based on charge time measurement, as described below.

You don't have to select any of these modes or tell the micro that you are measuring capacitance or inductance. The micro does everything automatically.

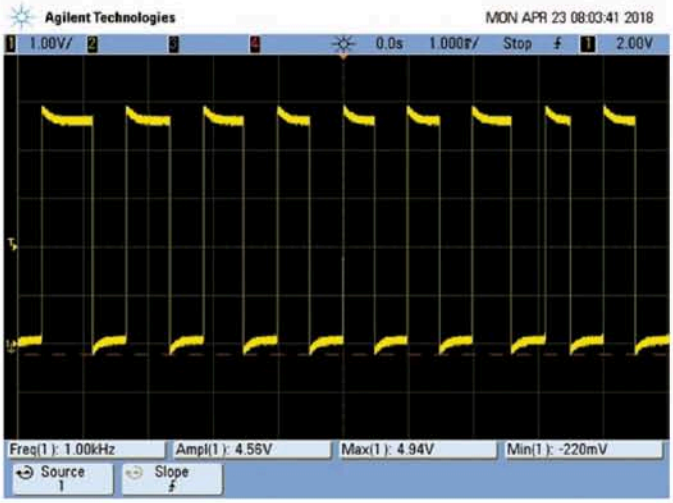
Displaying the results

Results are displayed on a 20x4 Alphanumeric LCD which is fitted with an I^2C adaptor so that only four connections to the Arduino are required: +5V power and ground, and the SDA and SCL pins for I^2C communications.

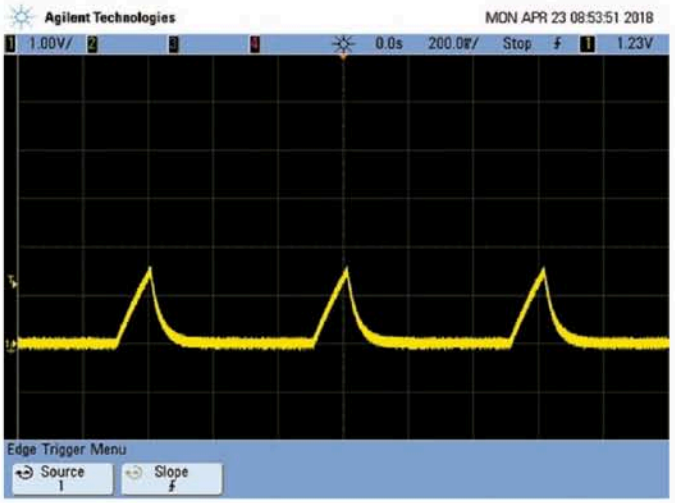
The four-line display constantly displays all the measurement data that you need to see and it even keeps a running average for super-accurate measurements.

It's powered from the Arduino's 5V rail, which can be derived from a USB charger, PC USB port or 9-12V DC plugpack via the on-board barrel connector.

The four reed relay coils are driven directly from the Arduino's digital output pins D6-D9. These outputs can provide more than enough current to latch a reed relay (up to 40mA) and the back-EMF at switch-off is sufficiently low that the ATmega328 IC's



Scope5: measuring a 0.5H (approximate) inductor. The frequency is down to 1kHz, but the oscillator is less stable – note that the pulse widths are varying significantly.



Scope6: a 220µF capacitor in RC mode. The measurement is repeated (about every second depending on the capacitor value) and the capacitor is discharged at the end of each cycle, to be ready for the next cycle.

internal clamp diodes are sufficient for absorbing it.

By the way, don't be tempted to substitute a different type of Arduino board. You need to use the Uno or equivalent.

This is because the Frequency Counter library that we use depends on pin D5 being fed into one of the hardware timers and this is only the case with the Uno.

Construction

The custom shield is built on a double-sided PCB measuring 68.5 x 53mm (ie, standard shield size) and coded 04106181.

The overlay diagram is shown in Fig.2 – use this and the matching photo as a guide during construction.

Start by fitting the resistors. While their values are printed on colour-coded bands, it's safer to simply measure the values with a DMM before soldering them in place. Next, mount the MKT/ceramic capacitors and inductor L1. None of these components are polarised.

What you wouldn't give to have an accurate L-C meter on hand right now!

While there are three holes for L1, only two are needed; the extra hole is to allow for variations in component size.

Ensure that one of the inductor leads goes through the hole closest to to the bottom edge of the PCB. The other lead can be soldered to either of the other pads.

Now fit the two tantalum capacitors. These are polarised; their positive leads will be identified with a "+"

Parts list – Ultra wide range, Arduino-based LC Meter

1 double-sided PCB, 68.5 x 53mm [Silicon Chip code 04106181]
1 set of Arduino stackable headers (1x6 pin, 2x8 pin, 1x10 pin, Jaycar HM3208)
1 Arduino Uno or equivalent [Altronics Z6280, Jaycar XC4410]
1 20x4 alphanumeric LCD [Jaycar QP5522, Silicon Chip SC4203]
1 I^2C Port Expander module [Jaycar XC3706]
1 100µH bobbin-style inductor [Altronics L6222, Jaycar LF1102]
4 5V coil DIL reed relays [Altronics S4100, Jaycar SY4030]
2 2-pin female header sockets (CON1,CON5)
1 black PCB-mounting right-angle banana socket (CON2) [Altronics P9201]
1 red PCB-mounting right-angle banana socket (CON3) [Altronics P9200]
1 4-pin female header socket (CON4)
1 2-pin header with shorting block (JP1)

Semiconductors

1 LM311 high-speed comparator, DIP-8 [Altronics Z2516, Jaycar ZL3311]

Capacitors

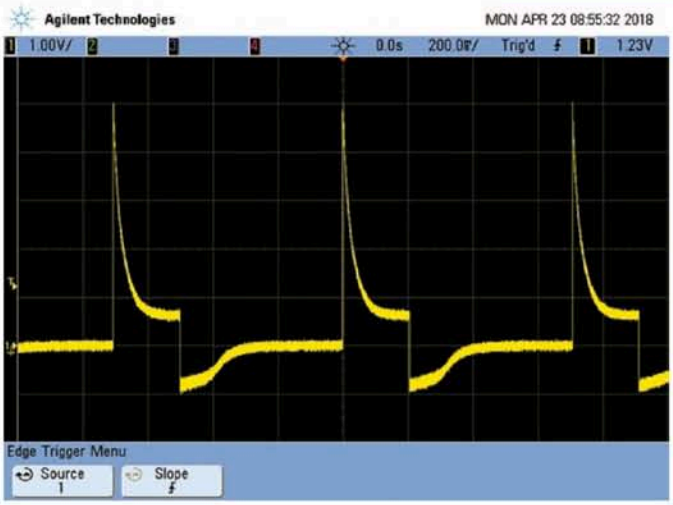
2 10µF 6.3V tantalum
1 100nF MKT or ceramic *(code 0.1µf; 104 or 100n)*
2 1nF 1% NP0/C0G ceramic or polystyrene* *(code 0.001µf; 102 or 1n)*
[Silicon Chip SC4273] **1% tolerance if possible*

Resistors (all 0.25W, 1% metal film)

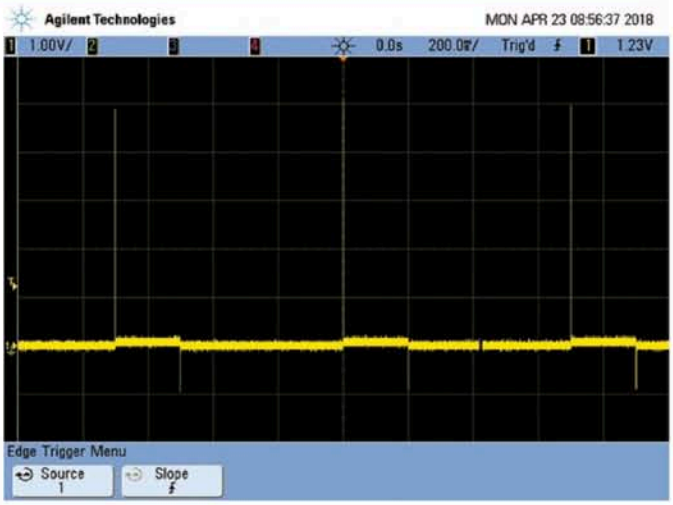
	4-band code (1%)	*5-band code (1%)*
3 100kΩ	*brown black yellow brown*	*brown black black orange brown*
1 47kΩ	*yellow violet orange brown*	*yellow violet black red brown*
1 6.8kΩ	*blue grey red brown*	*blue grey black brown brown*
1 4.7kΩ	*yellow violet red brown*	*yellow violet black brown brown*
1 1.3kΩ	*brown orange red brown*	*brown orange black brown brown*
1 130Ω	*brown orange brown brown*	*brown orange black black brown*

Case components (if required – see text)

1 laser-cut clear acrylic case (6 pieces) [Silicon Chip Part No SC4609]
4 small self-adhesive rubber feet
2 M3 x 15mm Nylon machine screws
4 M3 Nylon nuts
2 M3 Nylon washers
4 M3 x 25mm machine screws
2 M3 x 32mm machine screws
2 M3 x 15mm tapped spacers
4 M3 nuts



Scope7: measuring a 0.5H inductor in RL mode. Again, the cycle is repeated about once a second. The effects of the inductor's intrinsic resistance can be seen in that the voltage across the inductor does not fall completely to 0V.



Scope8: measuring a 26mH inductor in RL mode. Note that the spikes are very brief (of the order microseconds) and the slightly raised trace indicating the intrinsic resistance of the inductor is significant in this case too.

symbol printed on their bodies. Ensure the lead on this side goes to the pad marked "+" on the PCB, ie, closer to inductor L1.

We recommend that you solder IC1 directly to the board (ie, don't use an IC socket) to avoid socket contact resistance. Ensure the notched end is facing the top of the board before soldering it in place, as shown in Fig.2.

Now mount reed relays RLY1-RLY4. They are all identical and all have the same orientation. While they are in DIL packages, they should be soldered directly to the PCB. Again, this is to avoid socket contact resistance.

In each case, pin 1 faces towards the right-hand end of the PCB, away from the test sockets.

SIL socket CON1 is provided to allow small components to easily be tested as their leads can simply be pushed into the socket spring contacts. Take a two-way header socket and bend its pins by 90° close to the socket body, then solder it so that the socket projects off the end of the PCB. You can now solder the two banana sockets in place; CON3 is red while CON2 is black.

Mount the four-way and two-way header sockets for CON4 and CON5 next, along with the pin header for JP1. You can use the I²C module board as a jig to line up the sockets correctly. You may also need to straighten out the pins on the I²C breakout board, so they are facing downwards.

The final step in the shield construction is installing the headers to connect the shield to the Uno. We have used stackable headers, as they are slightly longer, giving some clearance between the Uno's USB socket and the TP+ test point.

The easier way to install the headers accurately is to assemble the headers, shield and Uno together and use the Uno's headers to line up the shield headers. Then turn it all upside down so that the shield rests on the headers as far away from the Uno as possible.

Tack solder the corner pins in place, then remove the Uno main board to allow easier access to the rest of the pins for soldering. Then refresh the corner pin solder joints.

If you don't already have the I²C breakout board fitted to the LCD, carefully line up pin 1 of the LCD with the I²C header end of the adaptor.

Solder one pin, then confirm that the boards are parallel and straight but not touching anywhere except the header before soldering the rest of the pins. The LCD assembly can now be plugged into CON4 and CON5. Alternatively, run four breadboard jumper leads between the I²C adaptor and CON4 for testing.

If you haven't yet adjusted the contrast on the LCD, this is easier to do when the board is connected by jumper leads.

Finally, push the assembled shield onto the Uno. This completes construction. Plug the Uno into your computer using a standard USB cable.

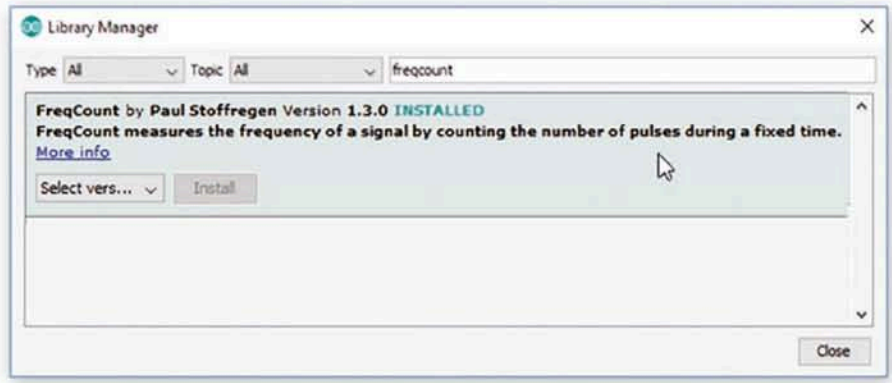


Fig.3: this shows how to find and install the frequency counter library in the Arduino IDE Library Manager. Type "freqcount" in the box at the upper right-hand corner of the window and then click the Install button that appears below (it's grey here because we have already installed it).

Loading the software

To compile and upload the software that runs on the Uno board, you need to have the Arduino IDE (Integrated Development Environment) software installed on your computer. The IDE can be downloaded from www.arduino.cc/en/main/software and it is available for Windows, macOS X and Linux. Download and install a version to suit your operating system and start the software.

The "sketch" or program that runs on the Uno needs two external libraries. One is used to count the pulses that are generated by the oscillator and the other to interface to the I²C LCD.

They are both supplied as ZIP files in the download package, along with the sketch itself.

Installing the first library is as simple as going to the Sketch -> Include Library -> Manage Libraries... menu, and searching for "freqcount", and clicking on the install option that is presented (see Fig.3).

To install the second library, search for "liquidcrystal_pcf8574" in the Library Manager, and install the version by Matthias Hertel.

Now open the sketch file, select "Arduino/Genuino Uno" under the Tools -> Board type... menu and then use the Tools ->Port menu to select the serial port that the Arduino is plugged into. Most versions of the Uno will display as COMx: (Arduino/Genuino Uno) in the dropdown menu, so you can use this hint to find the correct serial port if you are unsure.

Press Ctrl-U to compile and upload the sketch. If you see the message "Done Uploading" at the bottom of the window then everything has compiled and uploaded successfully.

If you get an error message, check that the libraries are installed correctly, and check that the correct serial port is selected.

Testing and set-up

If there is no back-light on the LCD, check that the LCD back-light jumper is installed on the I²C breakout board. If you are using the back-light header for mounting, the jumper is installed on the two pin header next to the mounting header.

If the back-light is working but there is no text, check and adjust the contrast pot on the back of the I²C breakout board. If you have no text or faint text, trying turning the pot clockwise. If you can only see white squares, try turning the pot anti-clockwise.

You should see text similar to that shown in Fig.4.

The unit stores calibration data in EEPROM. The first time you power it on after uploading the sketch, it will load a sensible set of defaults so you can start using it straight away. In the unlikely case that this does not happen, you can reset the calibration data

Fig.4: typical display on the LC Meter with no component connected. The small amount of residual capacitance shown can be adjusted for in calibration.

using the following procedure:

Open the serial monitor at 115,200 baud, and type "C" followed by Enter. When the menu appears, press "L", Enter, "S", Enter, then "X", Enter, and press the reset button on the Uno.

Now attach a component to the test terminals and check that you get a reading of its value.

Note that polarised components, such as electrolytic and tantalum capacitors should match their polarity to the test terminal markings. The test terminals (CON1, CON2/CON3) may have up to 5V present, so take care not to attach any components with lower ratings.

You may wish to improve the accuracy of the meter by measuring and entering specific values into the calibration values (assuming you have the means to do so). The values of C2 and the 130Ω and 1.3kΩ resistors are initially assumed to be very close to expected.

If they are not exact, and you have the means to measure them, you can improve the unit's accuracy by entering these into the calibration data, as we'll explain later.

Using it

On startup, the Uno performs the same calibration tests as the previous LC meter, storing the F1 reference oscillator frequency (just C1) and the F2 calibration frequency (C2 in parallel with C1).

During this time, the six calibration constants which are stored in EEPROM are displayed as they are loaded.

Initially, instead of waiting a full second to count the number of cycles out of the oscillator, the meter only counts for 100ms to save time.

This initial measurement is simply used to detect whether an inductor or capacitor is connected and whether its value falls in the range best measured by the time-constant method or the oscillator method.

If the frequency appears to be stable for two consecutive readings, the LC meter performs another test each cycle, this time taking one second for improved accuracy.

As long as the component remains connected, an average value is displayed by accumulating the results and dividing by the number of samples recorded. In this way, a highly accurate reading can be made.

The LC meter uses the first two lines to display its initial estimate for inductance and capacitance.

It displays both, as we found there were a small number of cases (with very large capacitance and inductance values) where the LC meter would detect one type of component as the other.

The measured oscillator frequencies are displayed to assist the user in following the operation of the LC meter. The third line displays whether the component is a capacitor or inductor, while the fourth line shows the averaged values and number of samples taken.

To use, simply connect the component across the leads and allow the reading to stabilise. Check that the component has been properly identified in the third line, and if you need an accurate value, allow a few readings to be recorded and read the average displayed on the fourth line.

Manual calibration

To access the calibration constants, you will need to connect to the serial port using a terminal program such as the Arduino IDE's serial monitor. The baud rate is 115,200 baud, with the standard Arduino defaults of 8bits, no parity and one stop bit.

See text on pages 35-36 for a full description of the LC Meter's modes.

After opening the terminal program send a "C" (capital) to enter calibration mode, pressing Enter if necessary to trigger sending of the line of data. The LC meter may take second or two to respond, as it only checks the serial port once every test loop.

The following menu appears:

```
Calibration Mode:
A:Enter R12 value – 130Ω
B:Enter R11 value – 1.3kΩ
C:Enter C2 value
D:Enter L1 value
E:Enter Cparasitic value
F:Enter Lparasitic value
G:Auto detect Cparasitic
  (leave terminals open circuit)
H:Auto detect Lparasitic
  (short circuit leads)
L:Load defaults
P:Print current values
S:Save to EEPROM
X:Exit calibration
Choose an option
```

So the procedure is select one of the 12 options from A to X.

Options A-F correspond to each of the six calibration constants. For A-D, the best way to improve the calibration is to measure the value of the component with an accurate meter and enter it. For example, to change the value of C2 to 1.1nF, type "C" (and Enter if necessary). You will be prompted:

```
C selected.
Enter a value:
```

Type a value, including any of the SI multipliers from p (pico) to G (giga). For 1.1nF, we simply type "1.1n", with the units being assumed. If the wrong units are included, or you enter a negative number, an error message will appear. Otherwise, you will see:

```
0.0000000011000F
C2 changed to 1.100000nF
```

The LC meter displays the entered value both with and without SI multipliers for clarity. At this point, the value is loaded into the program and will be used for measurements but it will not be saved in EEPROM for later use. To save the changes, select option "S".

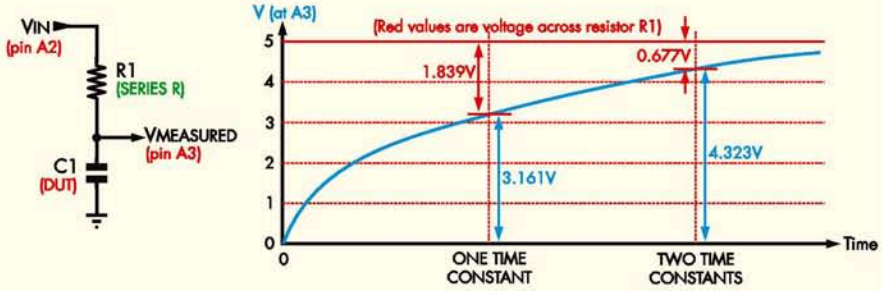
Mode	RLY1	RLY2	RLY3	RLY4
1. Calibration (C1 only)	OFF	ON	OFF	OFF
2. Calibration (C1 and C2)	ON	ON	OFF	OFF
3. Capacitor measurement	OFF	ON	ON	OFF
4. Inductor measurement	OFF	OFF	OFF	ON
5. Time constant mode	OFF	OFF	OFF	OFF

Table.1: relay states in each test mode

Measuring the value of large inductors and capacitors

If we connect a large inductor or capacitor to our test oscillator, it will fail to oscillate. Hence, we need an alternative method to handle these sorts of components to make the Meter truly useful. The simplest method is charge time measurement and we use digital output pins A0-A2, two fixed resistors (130Ω and 1.3kΩ) and analog input pin A3 to perform this function.

If we know the value of the resistor and capacitor in a series RC circuit, we can calculate its "time constant". This is simply the product of the resistance in ohms and the capacitance in farads, giving a value with units of seconds.



TIME CONSTANT METHOD FOR MEASURING CAPACITANCE

Fig.5: when testing high-value capacitors, C1 is charged via R1 and the voltage at pin A3 follows a curve similar to the blue one shown here. By measuring the voltage twice, and the time interval between measurements, we can determine its capacitance.

Refer to Fig.5. This shows the resistor and capacitor connected in the classic low-pass filter type arrangement. Assuming the capacitor starts fully discharged, the full applied voltage (Vin) appears across the resistor. After a period of one time constant, the voltage across the resistor will have fallen to Vin/e, where e is Euler's constant (2.718...).

In fact, regardless of what the voltage across the resistor is at the start, the ratio of the voltage at the start of the time constant period to the voltage at the end will be e.

This means we don't necessarily have to have the capacitor fully discharged to make our measurement, although we do get better accuracy if we work near this end of the curve, given the ~5mV resolution of the 10-bit ADC in the ATmega328 micro ($5V \div 2^{10}$).

To explain further, measuring over the first time constant period, the voltage across the resistor will drop from a nominal 5.000V down to 1.839V, a change of 3.161V or 647 ADC steps. Over the second time constant period, the voltage will change from 1.839V to 0.677V, a change of 1.163V or 238 ADC steps. Hence, starting with a mostly-discharged capacitor gives us better measurement resolution.

We don't even need to measure an exact multiple of the time constant to complete the calculations, as we can use a logarithmic function to convert a ratio of voltages into a corresponding number of time constants.

For example, if we measure the voltage across the resistor at two different times and compute the ratio between the two of 4.95, this is equivalent to $e^{1.6}$ and that tells us that the period between the two measurements is equal to 1.6 time constants. So if the period happens to be 80ms, we can calculate the time constant is 50ms.

And if we know the value of the resistance, then we can easily compute the capacitance. In this case, if the resistance is 1.3kΩ, since t = RC, C = t / R or 38.5µF.

A similar method for measuring the value of an inductor is shown in Fig.6. In this case, the curve is reversed and the equation for the time constant is the inductance in henries divided by the resistance in ohms.

Unlike capacitors, the ohmic resistance of a typical inductor can be quite significant and has to be taken into account in the calculation. With a capacitor, the voltage across the resistor will eventually get very close to 0V, only falling short due to leakage current, which is normally quite small. But with the inductor, in the steady state, the current is at a maximum and the voltage across it can be quite large.

Regardless, the method used is substantially the same; our starting state is with the inductor short-circuited to ensure no current is flowing, after which the series resistor is connected to 5V and the measurements of time and voltage begin.

After the time period has been measured, the series resistor is used to help determine the ESR of the inductor, and this is added to the series resistor's value before the time constant calculations are made, for improved accuracy.

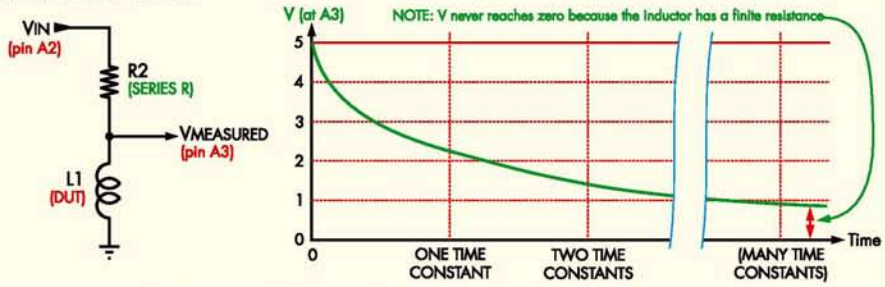
Practical measurement ranges

For capacitors above 1µF with a series resistor around 1kΩ, the time constant is around 1ms, which is well within the realm of what an Uno can measure with reasonable accuracy. This design has no theoretical upper limit to what capacitance it can measure, given enough time. In practice, we had no trouble reading capacitor values up to 100,000µF. (That's as big as we had!).

We also tried measuring really high-value inductors (in the henries). The oscillator-based method actually works with many of these but its operation does malfunction sometimes. Our time-constant method consistently gave results within the spread measured by an expensive commercial LC meter.

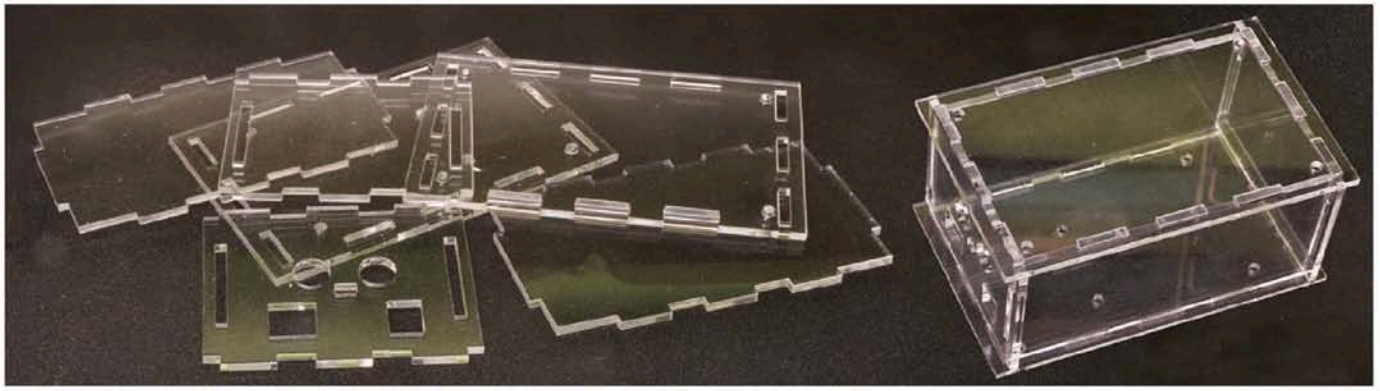
Note that the same commercial LC meter, using different test frequencies, gave wildly different values for inductance, varying by 10% or more. So it seems that the values of some components can vary quite dramatically depending on the frequency that they are tested at.

Keep that in mind when using this L-C Meter as the oscillator-based measurements are not at a fixed frequency.



TIME CONSTANT METHOD FOR MEASURING INDUCTANCE

Fig.6: similarly, when testing high-value inductors, the voltage at A3 initially starts out at 5V and drops to a value determined by its series resistance once L1's magnetic field is fully charged. By measuring the voltage twice, and the time interval between measurements, we can determine its inductance.



On the left are the six pieces which make up the case specifically designed for this LC Meter. They simply slot together and the PCB mounting screws hold them in place. The assmbled case is shown on the right. No cutout is necessary for the display as the case is clear acrylic. This case is available from the SILICON CHIP Online Shop for just $7.50 (Cat SC 4609)

Options "G" and "H" can be used to automatically detect stray capacitance and inductance.

When using option "G" , ensure that no components are attached, although it is fine to leave leads attached if they are normally used for measuring – they will contribute to stray capacitance, so this can be accounted for in this calibration. If you have leads, make sure they are open-circuit.

Option "G" simply runs a capacitance measurement on the leads (if connected), then saves this value to null future measurements.

Option "H" works in a similar fashion, although a shorting bar will need to be installed to create the effect of a zero inductance.

If you are using leads to measure in inductance mode, they can be shorted before selecting this option. Again, the value is saved and used to null inductance measurements. As with other values, these will need to be saved with option "S".

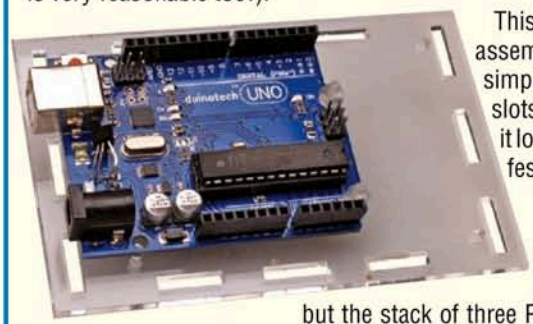
Option "L" loads sensible default values (but does not save them to EEPROM) and gets you back to the initial condition.

Option "P" displays the current values in use, while "X" returns to measurement mode.

You will notice that the LCD also echoes what is occurring on the serial monitor. SC

Assembly in the SILICON CHIP acrylic case

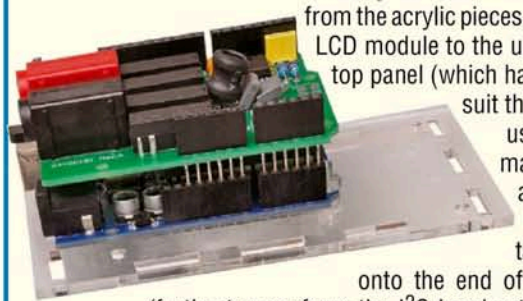
This assumes that you are using the recommended purpose-designed clear acrylic case* (available from the SILICON CHIP Online Shop at siliconchip.com.au/shop – cat no is SC-4609; price is very reasonable too!).



This case makes assembly so much simpler. It simply slots together. And it looks really professional!

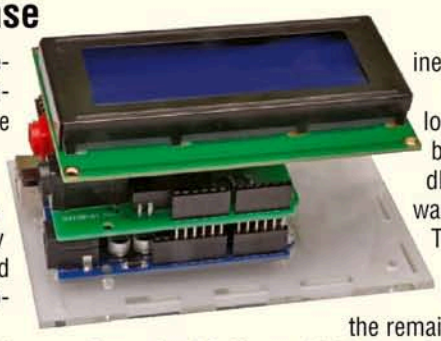
You *could* use a jiffy box like our earlier L-C meters but the stack of three PCBs does not easily lend itself to a UB3 case – and you also have a number of slots/holes to prepare.

The SILICON CHIP case has all required slots and holes already prepared for you.



Carefully remove the protective film from the acrylic pieces, and mount the LCD module to the underside of the top panel (which has four holes to suit the LCD module) using the 25mm machine screws and M3 nuts.

Thread the tapped spacers onto the end of the rightmost (furthest away from the I²C breakout board) machine screws by about 4mm.



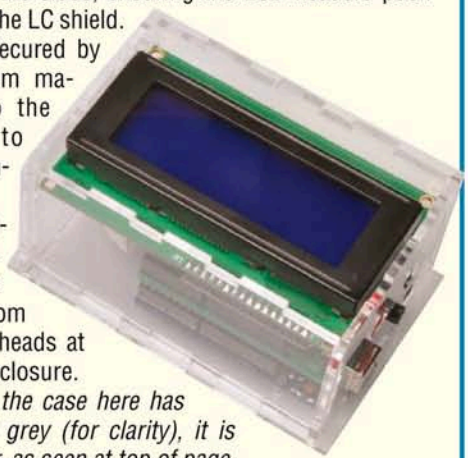
Attach the 15mm Nylon machine screws to the bottom panel in the middle holes using one Nylon washer and nut on each. This acts as a spacer.

Attach the Uno to the machine screws using the remaining two Nylon nuts.

Press the LC Meter shield onto the Arduino. Slot the end piece with the holes onto the Arduino, and drop it into the slots in the bottom panel, then fit the other three side panels so that the sides are all resting in the base.

Set the top onto the sides, ensuring the LCD headers push into the headers on the LC shield.

The halves are secured by threading the 32mm machine screws into the tapped headers to sandwich the assembly together.



We also recommend adding self-adhesive rubber feet to protect your desk from the exposed screw heads at the bottom of the enclosure.

**Note that while the case here has been photographed grey (for clarity), it is actually crystal clear, as seen at top of page.*

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NOTE: Not all PCBs are shown here due to space limits but the SILICON CHIP Online Shop has boards going back to 2001 and beyond. For a complete list of available PCBs etc, go to *siliconchip.com.au/shop/8* Prices are PCBs only, NOT COMPLETE KITS!

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(for CLASSiC-D Amp board and CLASSiC-D DC/DC Converter board refer above [Nov 2012/May 2013])			
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Li'l Pulser Mk2 Revised	JAN 2014	09107134	$15.00
10A 230VAC MOTOR SPEED CONTROLLER	FEB 2014	10102141	$12.50
NICAD/NIMH BURP CHARGER	MAR 2014	14103141	$15.00
RUBIDIUM FREQ. STANDARD BREAKOUT BOARD	APR 2014	04105141	$10.00
USB/RS232C ADAPTOR	APR 2014	07103141	$5.00
MAINS FAN SPEED CONTROLLER	MAY 2014	10104141	$10.00
RGB LED STRIP DRIVER	MAY 2014	16105141	$10.00
HYBRID BENCH SUPPLY	MAY 2014	18104141	$20.00
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	JUN 2014	01205141	$20.00
TOUCHSCREEN AUDIO RECORDER	JUL 2014	01105141	$12.50
THRESHOLD VOLTAGE SWITCH	JUL 2014	99106141	$10.00
MICROMITE ASCII VIDEO TERMINAL	JUL 2014	24107141	$7.50
FREQUENCY COUNTER ADD-ON	JUL 2014	04105141a/b	$15.00
TEMPMASTER MK3	AUG 2014	21108141	$15.00
44-PIN MICROMITE	AUG 2014	24108141	$5.00
OPTO-THEREMIN MAIN BOARD	SEP 2014	23108141	$15.00
OPTO-THEREMIN PROXIMITY SENSOR BOARD	SEP 2014	23108142	$5.00
ACTIVE DIFFERENTIAL PROBE BOARDS	SEP 2014	04107141/2	$10.00/set
MINI-D AMPLIFIER	SEP 2014	01110141	$5.00
COURTESY LIGHT DELAY	OCT 2014	05109141	$7.50
DIRECT INJECTION (D-I) BOX	OCT 2014	23109141	$5.00
DIGITAL EFFECTS UNIT	OCT 2014	01110131	$15.00
DUAL PHANTOM POWER SUPPLY	NOV 2014	18112141	$10.00
REMOTE MAINS TIMER	NOV 2014	19112141	$10.00
REMOTE MAINS TIMER PANEL/LID (BLUE)	NOV 2014	19112142	$15.00
ONE-CHIP AMPLIFIER	NOV 2014	01109141	$5.00
TDR DONGLE	DEC 2014	04112141	$5.00
MULTISPARK CDI FOR PERFORMANCE VEHICLES	DEC 2014	05112141	$10.00
CURRAWONG STEREO VALVE AMPLIFIER MAIN BOARD	DEC 2014	01111141	$50.00
CURRAWONG REMOTE CONTROL BOARD	DEC 2014	01111144	$5.00
CURRAWONG FRONT & REAR PANELS	DEC 2014	01111142/3	$30.00/set
CURRAWONG CLEAR ACRYLIC COVER	JAN 2015	SC2892	$25.00
ISOLATED HIGH VOLTAGE PROBE	JAN 2015	04108141	$10.00
SPARK ENERGY METER MAIN BOARD	FEB/MAR 2015	05101151	$10.00
SPARK ENERGY ZENER BOARD	FEB/MAR 2015	05101152	$10.00
SPARK ENERGY METER CALIBRATOR BOARD	FEB/MAR 2015	05101153	$5.00
APPLIANCE INSULATION TESTER	APR 2015	04103151	$10.00
APPLIANCE INSULATION TESTER FRONT PANEL	APR 2015	04103152	$10.00
LOW-FREQUENCY DISTORTION ANALYSER	APR 2015	04104151	$5.00
APPLIANCE EARTH LEAKAGE TESTER PCBs (2)	MAY 2015	04203151/2	$15.00
APPLIANCE EARTH LEAKAGE TESTER LID/PANEL	MAY 2015	04203153	$15.00
BALANCED INPUT ATTENUATOR MAIN PCB	MAY 2015	04105151	$15.00
BALANCED INPUT ATTENUATOR FRONT & REAR PANELS	MAY 2015	04105152/3	$20.00
4-OUTPUT UNIVERSAL ADJUSTABLE REGULATOR	MAY 2015	18105151	$5.00
SIGNAL INJECTOR & TRACER	JUNE 2015	04106151	$7.50
PASSIVE RF PROBE	JUNE 2015	04106152	$2.50
SIGNAL INJECTOR & TRACER SHIELD	JUNE 2015	04106153	$5.00
BAD VIBES INFRASOUND SNOOPER	JUNE 2015	04104151	$5.00
CHAMPION + PRE-CHAMPION	JUNE 2015	01109121/2	$7.50
DRIVEWAY MONITOR TRANSMITTER PCB	JULY 2015	15105151	$10.00
DRIVEWAY MONITOR RECEIVER PCB	JULY 2015	15105152	$5.00
MINI USB SWITCHMODE REGULATOR	JULY 2015	18107151	$2.50
VOLTAGE/RESISTANCE/CURRENT REFERENCE	AUG 2015	04108151	$2.50
LED PARTY STROBE MK2	AUG 2015	16101141	$7.50
ULTRA-LD MK4 200W AMPLIFIER MODULE	SEP 2015	01107151	$15.00
9-CHANNEL REMOTE CONTROL RECEIVER	SEP 2015	1510815	$15.00
MINI USB SWITCHMODE REGULATOR MK2	SEP 2015	18107152	$2.50
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	OCT 2015	01205141	$20.00
ULTRA LD AMPLIFIER POWER SUPPLY	OCT 2015	01109111	$15.00

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
ARDUINO USB ELECTROCARDIOGRAPH	OCT 2015	07108151	$7.50
FINGERPRINT SCANNER – SET OF TWO PCBS	NOV 2015	03109151/2	$15.00
LOUDSPEAKER PROTECTOR	NOV 2015	01110151	$10.00
LED CLOCK	DEC 2015	19110151	$15.00
SPEECH TIMER	DEC 2015	19111151	$15.00
TURNTABLE STROBE	DEC 2015	04101161	$5.00
CALIBRATED TURNTABLE STROBOSCOPE ETCHED DISC	DEC 2015	04101162	$10.00
VALVE STEREO PREAMPLIFIER – PCB	JAN 2016	01101161	$15.00
VALVE STEREO PREAMPLIFIER – CASE PARTS	JAN 2016	01101162	$20.00
QUICKBRAKE BRAKE LIGHT SPEEDUP	JAN 2016	05102161	$15.00
SOLAR MPPT CHARGER & LIGHTING CONTROLLER	FEB/MAR 2016	16101161	$15.00
MICROMITE LCD BACKPACK, 2.4-INCH VERSION	FEB/MAR 2016	07102121	$7.50
MICROMITE LCD BACKPACK, 2.8-INCH VERSION	FEB/MAR 2016	07102122	$7.50
BATTERY CELL BALANCER	MAR 2016	11111151	$6.00
DELTA THROTTLE TIMER	MAR 2016	05102161	$15.00
MICROWAVE LEAKAGE DETECTOR	APR 2016	04103161	$5.00
FRIDGE/FREEZER ALARM	APR 2016	03104161	$5.00
ARDUINO MULTIFUNCTION MEASUREMENT	APR 2016	04116011/2	$15.00
PRECISION 50/60Hz TURNTABLE DRIVER	MAY 2016	04104161	$15.00
RASPBERRY PI TEMP SENSOR EXPANSION	MAY 2016	24104161	$5.00
100DB STEREO AUDIO LEVEL/VU METER	JUN 2016	01104161	$15.00
HOTEL SAFE ALARM	JUN 2016	03106161	$5.00
UNIVERSAL TEMPERATURE ALARM	JULY 2016	03105161	$5.00
BROWNOUT PROTECTOR MK2	JULY 2016	10107161	$10.00
8-DIGIT FREQUENCY METER	AUG 2016	04105161	$10.00
APPLIANCE ENERGY METER	AUG 2016	04116061	$15.00
MICROMITE PLUS EXPLORE 64	AUG 2016	07108161	$5.00
CYCLIC PUMP/MAINS TIMER	SEPT 2016	10108161/2	$10.00/pair
MICROMITE PLUS EXPLORE 100 (4 layer)	SEPT 2016	07109161	$20.00
AUTOMOTIVE FAULT DETECTOR	SEPT 2016	05109161	$10.00
MOSQUITO LURE	OCT 2016	25110161	$5.00
MICROPOWER LED FLASHER	OCT 2016	16109161	$5.00
MINI MICROPOWER LED FLASHER	OCT 2016	16109162	$2.50
50A BATTERY CHARGER CONTROLLER	NOV 2016	11111161	$10.00
PASSIVE LINE TO PHONO INPUT CONVERTER	NOV 2016	01111161	$5.00
MICROMITE PLUS LCD BACKPACK	NOV 2016	07110161	$7.50
AUTOMOTIVE SENSOR MODIFIER	DEC 2016	05111161	$10.00
TOUCHSCREEN VOLTAGE/CURRENT REFERENCE	DEC 2016	04110161	$12.50
SC200 AMPLIFIER MODULE	JAN 2017	01108161	$10.00
60V 40A DC MOTOR SPEED CON. CONTROL BOARD	JAN 2017	11112161	$10.00
60V 40A DC MOTOR SPEED CON. MOSFET BOARD	JAN 2017	11112162	$12.50
GPS SYNCHRONISED ANALOG CLOCK	FEB 2017	04202171	$10.00
ULTRA LOW VOLTAGE LED FLASHER	FEB 2017	16110161	$2.50
POOL LAP COUNTER	MAR 2017	19102171	$15.00
STATIONMASTER TRAIN CONTROLLER	MAR 2017	09103171/2	$15.00/set
EFUSE	APR 2017	04102171	$7.50
SPRING REVERB	APR 2017	01104171	$12.50
6GHz+ 1000:1 PRESCALER	MAY 2017	04112162	$7.50
MICROBRIDGE	MAY 2017	24104171	$2.50
MICROMITE LCD BACKPACK V2	MAY 2017	07104171	$7.50
10-OCTAVE STEREO GRAPHIC EQUALISER PCB	JUN 2017	01105171	$12.50
10-OCTAVE STEREO GRAPHIC EQUALISER FRONT PANEL	JUN 2017	01105172	$15.00
10-OCTAVE STEREO GRAPHIC EQUALISER CASE PIECES	JUN 2017	SC4281	$15.00
RAPIDBRAKE	JUL 2017	05105171	$10.00
DELUXE EFUSE	AUG 2017	18106171	$15.00
DELUXE EFUSE UB1 LID	AUG 2017	SC4316	$5.00
MAINS SUPPLY FOR BATTERY VALVES (INC. PANELS)	AUG 2017	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEPT 2017	01108171	$20.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER PANELS	SEPT 2017	01108172/3	$20.00/pair
3-WAY ADJUSTABLE ACTIVE CROSSOVER CASE PIECES	SEPT 2017	SC4403	$10.00
6GHz+ TOUCHSCREEN FREQUENCY COUNTER	OCT 2017	04110171	$10.00
KELVIN THE CRICKET	OCT 2017	08109171	$10.00
6GHz+ FREQUENCY COUNTER CASE PIECES (SET)	DEC 2017	SC4444	$15.00
SUPER-7 SUPERHET AM RADIO PCB	DEC 2017	06111171	$25.00
SUPER-7 SUPERHET AM RADIO CASE PIECES	DEC 2017	SC4464	$25.00
THEREMIN	JAN 2018	23112171	$12.50
PROPORTIONAL FAN SPEED CONTROLLER	JAN 2018	05111171	$2.50
WATER TANK LEVEL METER (INCLUDING HEADERS)	FEB 2018	21110171	$7.50
10-LED BARAGRAPH	FEB 2018	04101181	$7.50
10-LED BARAGRAPH SIGNAL PROCESSING	FEB 2018	04101182	$5.00
TRIAC-BASED MAINS MOTOR SPEED CONTROLLER	MAR 2018	10102181	$10.00
VINTAGE TV A/V MODULATOR	MAR 2018	02104181	$7.50
AM RADIO TRANSMITTER	MAR 2018	06101181	$7.50
HEATER CONTROLLER	APR 2018	10104181	$10.00
DELUXE FREQUENCY SWITCH	MAY 2018	05104181	$7.50
USB PORT PROTECTOR	MAY 2018	07105181	$2.50
2 x 12V BATTERY BALANCER	MAY 2018	14106181	$2.50
USB FLEXITIMER	**JUNE 2018**	**19106181**	**$7.50**
WIDE-RANGE LC METER	**JUNE 2018**	**04106181**	**$5.00**
WIDE-RANGE LC METER CLEAR CASE PIECES	**JUNE 2018**	**SC4609**	**$7.50**
TEMPERATURE SWITCH MK2	**JUNE 2018**	**05105181**	**$7.50**
LiFePO4 UPS CONTROL SHIELD	**JUNE 2018**	**11106181**	**$5.00**

SWITCH ON OR OFF WHEN IT'S TOO HOT OR TOO COLD

- Monitors from -10°C to +125°C
- Resolution: 1°C up to 100°C; 2°C for 100-125°C
- Adjustable hysteresis
- Accuracy: typically ±2°C
- Two sets of relay contacts to control two individual devices

By John Clarke

Temperature Switch Mk2

Turn on a pump or fan if something is too hot... or turn on a heater if it's too cold. Two sets of changeover contacts allow a flexible switching arrangement. All you need to set it up is a multimeter.

There are many instances where you may want to switch something on or off at a certain temperature. You could be switching a fan, pump, light, alarm, heater, cooler or something else. Our new Temperature Switch Mk2 can do any of these tasks. You can use it in automotive, household and industrial applications.

If switching the load directly, the Temperature Switch can be used for devices that have a supply voltage up to 30V DC or AC and draw up to 5A (or 8A if the specified Altronics relay is used).

If you want to switch mains-powered devices you will need a separate 250VAC-rated relay, contactor or solid state relay.

The Temperature Switch's relay can be energised when the temperature goes above (or below) a particular threshold, which is set using a trimpot (VR1). Then you can set a lower (or higher) threshold temperature with another trimpot (VR2).

Why do you need two temperature settings? In practice, if you have just one temperature setting, the relay may switch rapidly on and off (chatter) as the temperature changes by very small amounts near your preset temperature.

The difference between the two temperature settings can be as little as 1°C but in practice you would go for a larger difference to stop the relay from switching too frequently. In effect, these two temperature thresholds provide hysteresis for the circuit.

For example, you could set the unit to energise the relay if the sensed temperature goes above 60°C but once it has been energised, it can be set to remain energised until the temperature drops below 55°C.

If the relay is connected to a fan, that will ensure that it runs for a minimum period before switching off, ie, the time taken to reduce the temperature by 5°C.

- Switches a relay if the temperature goes above (or below) a preset value and keeps it on until the temperature drops below (or goes above) a second preset value
- Relay contact rating of up to 30VAC/DC at 5A or 8A (see parts list)
- Adjustable hysteresis is set with an upper and lower threshold
- Switching temperature can be anywhere from -10°C to +125°C
- Power supply: 12-15V DC at up to 60mA; quiescent current 20mA
- Indicators: power on LED1, relay energised LED2
- Thermistor temperature reading between TP4 and TPREF, 10mV/°C

Sensing the temperature

We use a low-cost negative temperature coefficient (NTC) thermistor to measure temperature. This is a two-lead device with a resistance that varies with temperature. As it gets hotter, its resistance drops. It can be attached to an object to sense its temperature (eg, a heatsink).

You can get waterproof thermistors which can be immersed in liquid, or you could waterproof a standard NTC thermistor. You can also get lug-mount

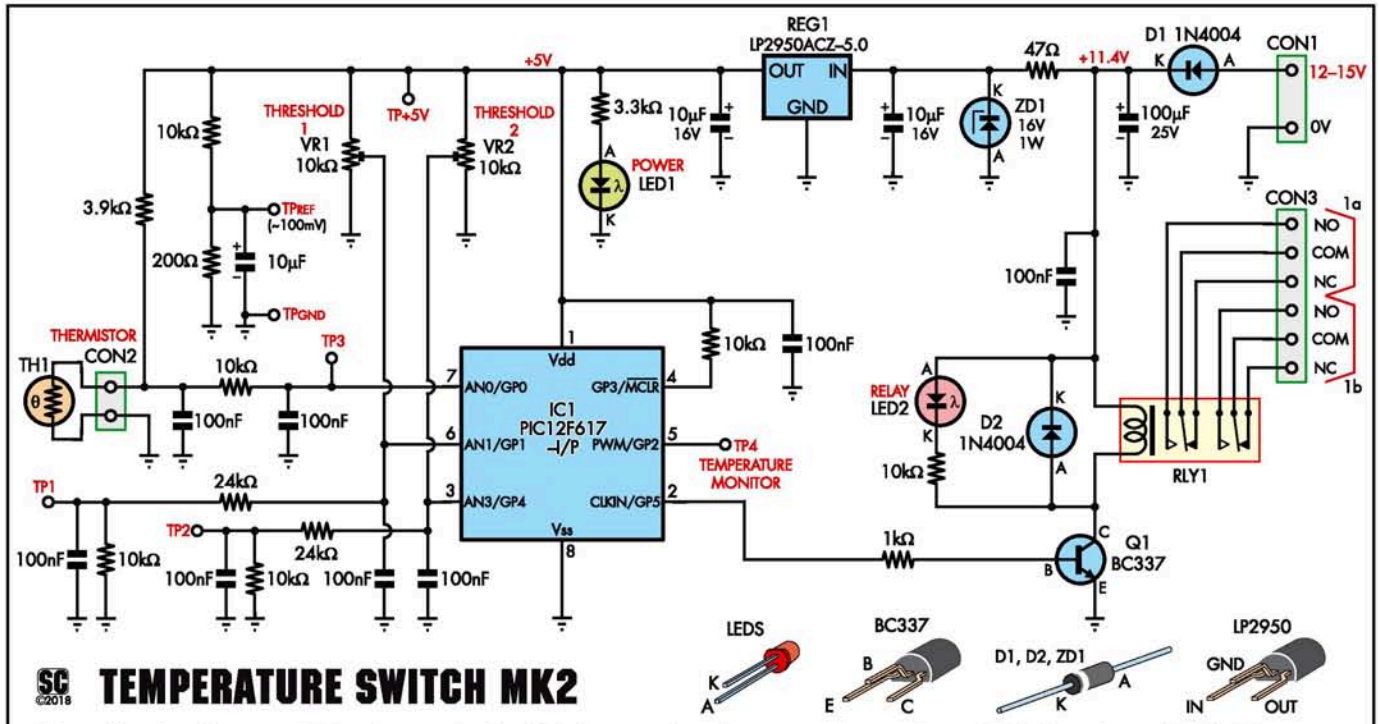


Fig.1: the circuit uses a PIC microcontroller (IC1) to monitor the temperature via an NTC thermistor (TH1). IC1 compares the measured temperature to the thresholds set by trimpots VR1 & VR2 to decide when to energise RLY1.

NTC thermistors which can easily be attached to a flat surface using a screw or bolt.

Circuit description

The full circuit of the Temperature Switch is shown in Fig.1. It's based on IC1, an 8-pin PIC12F617 microcontroller that includes an internal analog-to-digital (ADC) converter with four multiplexed inputs and a PWM (pulse-width modulation) generator.

The NTC thermistor TH1 is connected across CON2 and it forms a voltage divider in combination with the 3.9kΩ resistor from the +5V rail. Therefore the voltage across TH1 will drops as the temperature rises.

This voltage is stabilised by a 100nF capacitor connected across the pins of CON2 and it has more filtering provided by another RC low-pass filter comprising a 10kΩ resistor and second 100nF capacitor, before being fed to input pin 7 of IC1.

Pin 7 is set up as the AN0 analog input and IC1 can read the voltage at this pin using its internal 10-bit ADC, with a resolution of approximately 5mV ($5V \div 2^{10}$).

It then uses a look-up table to convert the voltage reading into a temperature. This is necessary since the relationship between temperature and resistance of TH1 is non-linear.

The two threshold temperatures are set using trimpots VR1 and VR2 which are connected across the 5V supply rail. Their wipers go to analog input pins 6 (AN1) and 3 (AN3) and the setting of each potentiometer determines the voltage at these pins, ie, 0-5V. See the section below for an explanation of how these voltages correspond to temperatures.

The 100nF capacitors connected from each analog input to ground provide a low source impedance for the ADC.

IC1 converts the voltages at pins 3 and 6 to digital values and then into temperatures. It then compares the sensor temperature to the upper and lower switching thresholds, to decide whether relay RLY1 should be energised. It drives digital output pin 2 (GP5) high to energise the relay or low to de-energise it.

When pin 2 is high, NPN transistor Q1 is turned on to energise the coil of relay RLY1, pulling in its armature and connecting the COM and NO contact pairs on CON3.

The 1kΩ base resistor sets the base current for Q1 to 4mA. LED2, connected across the coil of RLY1 via its 10kΩ series resistor, lights to show when the relay is energised.

When transistor Q1 is turned off to switch off the relay, diode D2 absorbs the voltage generated by the collapsing magnetic field in its coil. This protects Q1 from any back-EMF spike voltages.

The DC power source is connected to CON1 and can be in the range of 12-15V DC. Diode D1 provides supply reverse polarity protection. The voltage at D1's cathode is (nominally) around 11.4V and this is used to drive the coil of RLY1.

The 100µF electrolytic capacitor filters the supply, and voltage transients are safely clamped using a 16V zener diode (ZD1). Current through ZD1 is limited by the series 47Ω resistor.

The 3-terminal regulator REG1 provides a regulated 5V supply rail for IC1 and TH1. LED1 is connected across the 5V supply with a 3.3kΩ current-limiting resistor and lights whenever the unit is powered up.

IC1's $\overline{\text{MCLR}}$ reset input is tied to the 5V supply via a 10kΩ resistor to provide a power on reset for the microcontroller.

Relationship between temperature and voltage

We mentioned earlier that trimpots VR1 and VR2 can be adjusted to provide a voltage of 0-5V to IC1, corresponding to temperature thresholds that can be set in the range of -10°C to +125°C. So how do you adjust the trimpots for each temperature?

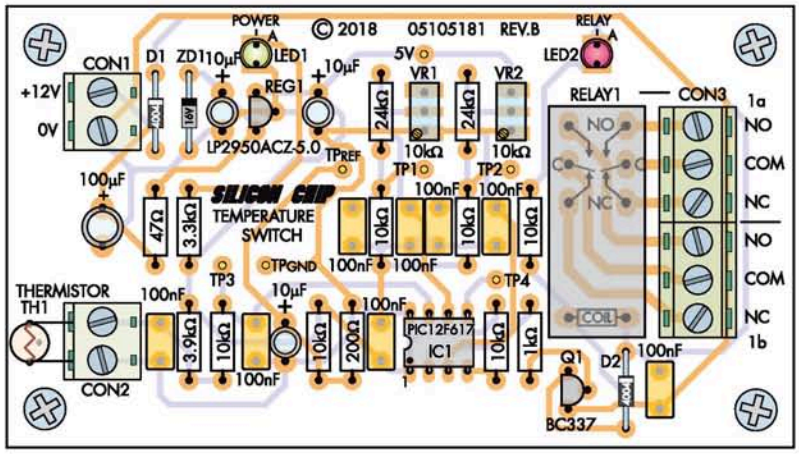
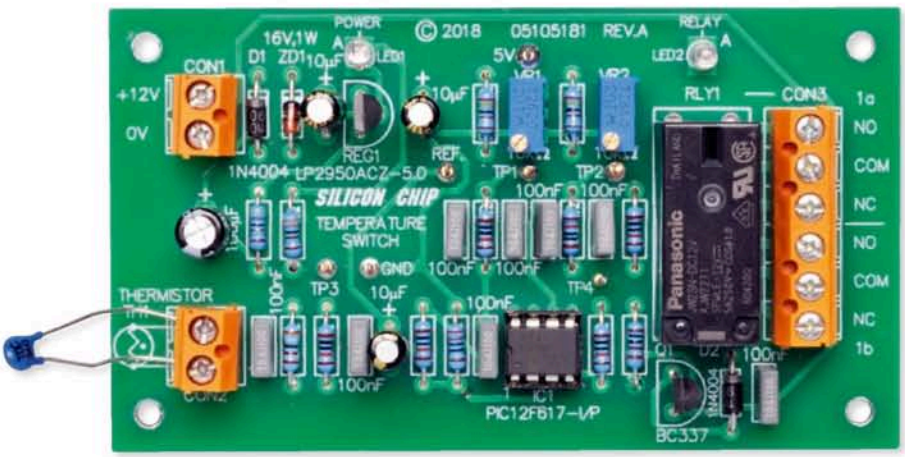


Fig.2: compare this component layout for the Temperature Switch Mk2 with the completed prototype PCB shown below when building the project. If you need to use the Temperature Switch Mk2 to switch on/off mains-powered devices, you have to substitute RLY1 with a 250VAC-rated DPDT relay, which must be mounted off the PCB.



The short answer is that you connect the negative lead of your digital multimeter to the test point marked TPREF. (It is biased to around 100mV above ground using a 10kΩ/200Ω resistive divider across the 5V supply rail). The positive lead of your DMM then goes to TP1 (for setting trimpot VR1) or TP2 (for setting VR2).

By connecting the negative lead of your DMM to TPREF, you will get a negative reading at test points TP1 and TP2 when trimpots VR1 and VR2 are set close to their fully anti-clockwise positions. This allows you to set temperature thresholds below 0°C.

The 24kΩ/10kΩ resistive dividers between AN1/AN3 and TP1/TP2 cause the voltages that you read with your multimeter at TP1 and TP2 to change by 10mV for each 1°C adjustment. So you can simply read the voltage (in mV) between TP1 and TPREF or TP2 and TPREF and then divide by ten to convert from the voltage reading to a temperature. For example, 300mV = 30.0°C, 472mV = 47.2°C etc.

So the 100mV value at TPREF allows for up to a -10°C adjustment where a reading at TP1/2 will be -100mV. The maximum setting of VR1/VR2 gives a reading at the relevant test point of 1.37V (5V ÷ [24kΩ ÷ 10kΩ + 1] - 100mV) or 1370mV, corresponding to +137.0°C. This confirms that we can set the thresholds up to the +125°C maximum that the unit can handle.

We considered using a scaling factor of 1mV = 1°C but were concerned that some DMMs may be inaccurate when reading small voltages. We were also concerned that this could result in increased inaccuracy due to noise and EMI that could be picked up by the meter.

Note that we feed the voltage at the wipers of VR1 and VR2 directly to IC1, rather than sensing the divided-down voltages at TP1 and TP2. This allows us to use the full 10-bit resolution of IC1's ADC, giving better accuracy. The equivalent scaling is done in the software so that the temperature thresholds match the readings at TP1 and TP2.

Monitoring temperatures

So that you can monitor the current sensor temperature easily, the PWM output at pin 5 is driven with a 3.9kHz square wave with a duty cycle that is proportional to temperature. When you connect a DMM between this pin and TPREF, it will internally average out the PWM signal to give a DC voltage reading. This also has a scaling factor of 10mV/°C.

So if you get a reading of say 275mV between TP4 and TPREF, that corresponds to a temperature of 27.5°C (275mV ÷ 10mV). If you want to measure the voltage across the thermistor itself, you can do so between TP3 and GND.

Selecting a thermistor

The thermistor we used has a reference resistance of 10kΩ at 25°C and a beta value of 4100. 10kΩ NTC thermistors are very common so you shouldn't have trouble finding a suitable sensor.

The beta value determines the shape of the temperature/resistance curve. While beta values vary from device to device, it is very common to find NTC thermistors with a beta close to 4000. As long as yours is in the range of 3900-4200 then it should give similar results to the one used in our prototype.

We generated the temperature look-up table for our firmware using this online calculator: **siliconchip.com.au/link/aaj1**

If you want higher accuracy

Although general-purpose NTC thermistors are typically accurate to within a few degrees Celsius, if you want higher accuracy, use a thermistor with tight tolerances such as the AVX NJ28NA0103FCC. This has a 1% tolerance at 25°C and a beta value of 4100, also with a 1% tolerance. It is available from RS: **siliconchip.com.au/link/aaf7**

This thermistor is not encapsulated. For remote temperature measurement, you can extend the leads. Use insulation sleeving (eg, heatshrink tubing) over the wire connections. For attachment to a solid object, the thermistor can be epoxy glued to the object or clamped against it. For outdoor use

or immersion in liquid, insulate the thermistor assembly using neutral-cure silicone sealant.

Note that if extending the leads over long distances, even if the wires add a resistance of more than 10Ω, this is still only a 0.1% error at 25°C; although the error will increase at higher temperatures. So check the total ("round-trip") resistance before wiring the thermistor to a very long cable.

Construction

The Temperature Switch Mk2 is built on a double-sided PCB coded 05105181 measuring 104 x 58.5mm. It can be housed in a UB3 129 x 68 x 43mm Jiffy box, mounted on short spacers.

Use the overlay diagram, Fig.2, as a guide during construction. Fit the resistors first. These have colour-coded bands, as shown in Table.1 but we suggest that you use a DMM set to measure ohms to check the values, as the colour bands can be easily misinterpreted.

Diodes D1, D2 and ZD1 are installed next and these need to be inserted with the correct polarity, ie, with the striped end (cathode, "k") oriented as shown in Fig.2. Both diodes are 1N4004 types while the zener diode (ZD1) is a 1N4745 or equivalent.

We recommend using an IC socket for IC1. Take care with orientation when installing the socket and when inserting the IC. Note that IC1 needs to be programmed with the software for the Temperature Switch before use. A programmed IC can be obtained from the SILICON CHIP Online Shop (search for it by code or month).

Alternatively, you can program a blank chip yourself using the HEX file which is available from the SILICON CHIP website (free for subscribers).

For the test points, we used five PC stakes. One for TPGND and the others for TPREF, TP1, TP2, TP3 and TP4. If left as bare pads, they can be probed directly using standard DMM leads.

The capacitors are mounted next. The electrolytic types must be inserted with the polarity shown (longer lead is positive, with a stripe on the can indicating the negative lead). Install transistor Q1 and regulator REG1 now and take care not to mix them up as they have the same package.

Now fit trimpots VR1 and VR2. They may be marked with code 103. Orient these with the adjusting screw as shown in Fig.2, toward IC1.

Install terminal blocks CON1, CON2 and CON3 now. CON1 and CON2 are 2-way types which are mounted separately while CON3 comprises two 3-way screw connectors dovetailed together. Fit all three connectors with the wire entry to the outside edge of the PCB.

Finally, the LEDs and RLY1 can be mounted. We placed the LEDs close to the PCB but they can be mounted higher or even off the PCB, for example, chassis-mounted to the case.

If mounting them off-board, wire them to the LED pads with flying leads. The LEDs must be oriented correctly with the anode (longer lead) of the LED to the pad marked "A" on the PCB.

Although presented as a bare PCB, the Temperature Switch can be installed within a UB3 box. Mark out and drill the 3mm holes in the box, corresponding to the corner mounting holes on the PCB, then attach it to the box using short spacers and screws. Holes will be required at each end of the box (or on the lid) for cable glands, which the power supply, thermistor and relay wiring will pass through.

Testing

You will need a 12-15V DC supply at up to 60mA. Connect the power supply

Parts List

1 double-sided PCB, coded 05105181, 104 x 58.5mm
1 DPDT 12V DC coil relay (RLY1)
[Jaycar SY4052 (5A) or Altronics S4270A (8A)]
1 10kΩ NTC thermistor with beta ~4100; see text (TH1) [Jaycar RN3440]
2 2-way screw terminals with 5.08mm pin spacing (CON1,CON2)
2 3-way screw terminals with 5.08mm pin spacing (CON3)
1 DIL 8-pin IC socket for IC1
7 PC stakes (optional) (TPGND,TP1,TP2,TP3,TP4 & TPREF)
1 UB3 jiffy box, spacers and mounting screws (optional)

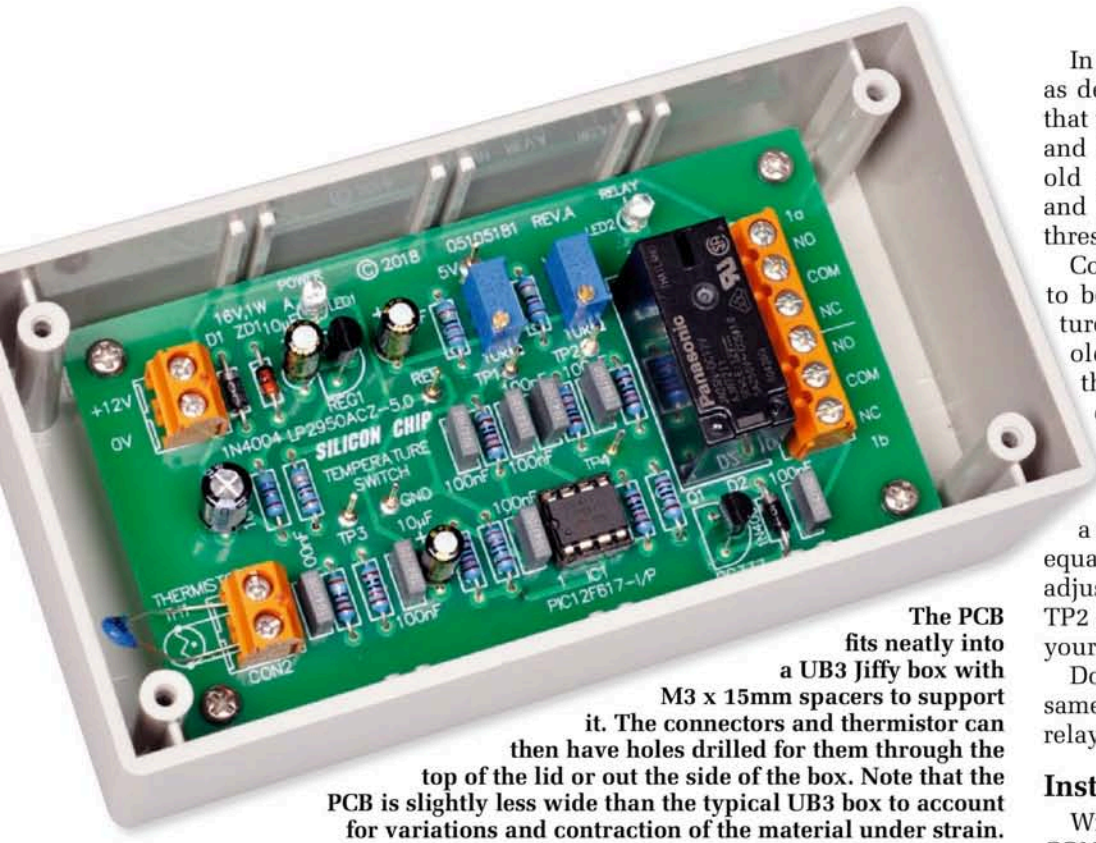
Semiconductors
1 PIC12F617-I/P programmed with 0510518A.HEX (IC1)
1 LP2950ACZ-5.0 regulator (REG1)
1 BC337 NPN transistor (Q1)
1 16V 1W (1N4745) zener diode (ZD1)
2 1N4004 1A diodes (D1,D3)
2 3mm LEDs (LED1,LED2)

Capacitors
1 100µF 25V PC electrolytic
3 10µF 16V PC electrolytic
8 100nF 63/100V MKT polyester

Resistors (all 1%, 0.25W)
2 24kΩ
6 10kΩ
1 3.9kΩ
1 3.3kΩ
1 1kΩ
1 200Ω
1 47Ω
2 10kΩ multi-turn vertical trimpots (3296W style) (VR1,VR2)

Table.1: Resistor Colour Codes

	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	24kΩ	red yellow orange brown	red yellow black red brown
❑	6	10kΩ	brown black orange brown	brown black black red brown
❑	1	3.9kΩ	orange white red brown	orange white black brown brown
❑	1	3.3kΩ	orange orange red brown	orange orange black brown brown
❑	1	1kΩ	brown black red brown	brown black black brown brown
❑	1	200Ω	red black brown brown	red black black black brown
❑	1	47Ω	yellow violet black brown	yellow violet black gold brown



The PCB fits neatly into a UB3 Jiffy box with M3 x 15mm spacers to support it. The connectors and thermistor can then have holes drilled for them through the top of the lid or out the side of the box. Note that the PCB is slightly less wide than the typical UB3 box to account for variations and contraction of the material under strain.

to CON1 and the thermistor to CON2.

Leave IC1 out of its socket before switching the power supply on. LED1 should light. Now measure the voltage between TP+5V and TPGND. The reading should be between 4.975V and 5.025V. Next, check the voltage between TPREF and TPGND. It should be between 96.5mV and 99.5mV, ideally close to 98mV.

If these voltages are correct, then switch the supply off and insert IC1, taking care to orient it correctly.

Switch the power back on and measure the voltage between TP4 and TPREF. Check that this corresponds to room temperature, keeping in mind the 10mV/°C scaling factor.

To test the switching operation, connect your DMM between TP2 and TPREF, then adjust VR2 for a reading that is a few tens of millivolts above the reading at TP4. For example, if you read 220mV at TP4 (corresponding to 22°C), adjust VR2 for 260mV at TP2 (corresponding to 26°C).

Now connect your DMM between TP1 and TPREF and adjust VR1 for an intermediate reading, eg, 240mV corresponding to 24°C.

At this point, RLY1 should not be energised. Heat up the thermistor and the relay should be energised; you should hear it click and LED2 will light up. Then cool the thermistor down and it should click again as it's de-energised.

Depending on the ambient temperature, you may be able to heat up the thermistor by simply holding it between two fingers. Or you could use a cigarette lighter, with the flame briefly held below the thermistor body

Setting the thresholds

Now determine the temperatures at which you want the relay to be energised and de-energised.

If you want the relay energised when the temperature rises above a particular threshold then this temperature becomes your upper threshold. Subtract your desired hysteresis value (in °C) from the upper threshold to determine the lower threshold.

In this case, use the same procedure as described under Testing above so that the voltage reading between TP1 and TPREF equals the lower threshold and the reading between TP2 and TPREF equals the desired upper threshold.

Conversely, if you want the relay to be energised when the temperature falls below a particular threshold then this will be your lower threshold and you should add the desired amount of hysteresis to it, to determine the upper threshold value.

In this case, adjust VR1 to give a reading between TP1 and TPREF equal to your upper threshold and adjust VR2 to give a reading between TP2 and TPREF that corresponds to your lower threshold.

Do not set both thresholds to the same temperature as this will cause relay chatter.

Installation

Wire your power supply leads to CON1. For use in a motor vehicle, use automotive-rated wire with the +12V terminal connected to the switched side of the ignition. That way, your battery won't be drained when the ignition switch is off.

The 0V terminal on CON1 should be connected to the vehicle chassis (assuming you have a negative chassis, like all modern vehicles) using a crimp eyelet secured to a convenient screw terminal. You may need to drill a separate hole for this connection if you can't utilise an existing earth connection.

Note that while the test points can show readings with a resolution greater than 1°C (252mV for 25.2°C) the Temperature Switch will only switch RLY1 on and off at the temperature settings and readings rounded **up** to the nearest degree.

Previous temperature control projects published in SILICON CHIP

- Infrared-Sensing Heater Controller for convection and bar radiators up to 10A, 50/60Hz and 230VAC, with temperature control from 15°C to 31°C. You can even add a thermopile for added precision (April 2018; siliconchip.com.au/Article/11027) [PCB 10104181 – $10].
- Need to convert a freezer into a fridge, or even a fridge into a wine cooler? Try the TempMaster Thermostat Mk3 (August 2014; siliconchip.com.au/Article/7959) [PCB: 21108141 – $15 | Jaycar KC5529].
- High-temperature applications like ovens or kilns (below 1200°C) or even freezing cold (above -50°C)? Try the High-temperature Thermometer/Thermostat (May 2012; siliconchip.com.au/Article/674) [PCB 21105121 – $20]. SC

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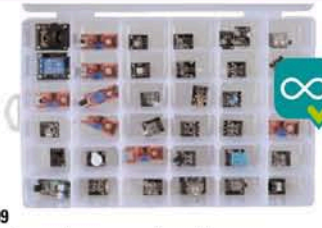

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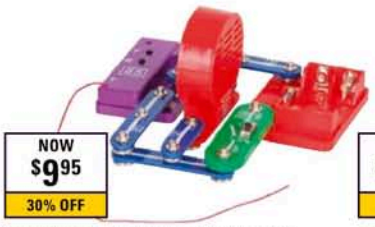

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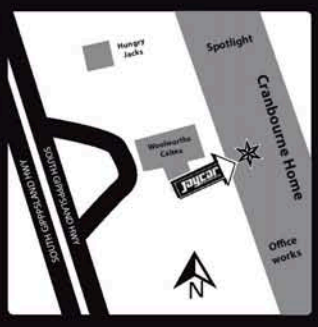

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SERVICEMAN'S LOG

Repairing 'proper' stereo gear is satisfying

Dave Thompson*

I am sorry but I don't think much of a lot of modern consumer gear. It is not built to last and it generally is not worth trying to repair. Give me the 'proper' stuff made in Japan, America and Europe in those halcyon years between 1970 and 1990 – or thereabouts!

For as long as I can remember, I've been either building or repairing electrical and electronic hardware and, in that time, I've encountered many kindred souls who share my views that in certain circumstances, older devices are superior to their modern-day counterparts.

This is fortunate for a serviceman, because these people are happy to spend money on repairs rather than simply splashing out on something new.

While some may put this down to that time-honoured, generational phenomenon where we think that our first, 5-valve mantle or 7-transistor pocket radio sounded way better than any of this modern digital rubbish, and that this rose-tinted view is just nostalgia, I'm not too sure.

Obviously, this theory doesn't hold true with every device ever made – mobile phones and DVD-burners are two that immediately spring to mind – and it's clear that many other modern devices far outperform their older versions in almost every respect, but it doesn't take much digging to find some good examples.

Take hifi stereo amplifiers; robotically mass-produced, cheap, modern units often can't hold a candle to their 70s, 80s and some 90s hand-assembled counterparts.

On paper, even the most basic modern amplifier out-performs older amps, but as any audio aficionado will tell you (often at great length), a system's sound isn't just about having an amplifier with an output of 750W RMS per channel, a THD figure of 0.00000001% and a signal-to-noise ratio of -1000dB.

Don't get me wrong; building or even designing an amp with those specs (although I might have exaggerated just a touch there) is a huge achievement and something that could only be possible using today's technology, but I've seen too many expensive systems with specs that would make an audiophile's heart flutter that sound terrible to my admittedly rock-and-roll pounded ears.

Sound is so subjective; I once flatted with a guy who was also into music, and we shared my stereo sound system. No problem with that, however when I built and added an ETI 10-band per channel stereo graphic equaliser and set it up, I'd come home to find 'my' EQ settings had been changed to 'his' settings. We had very different ideas as to what sounded 'good'.

The owners of hyper-specced and similarly-priced audiophile systems often get their kicks not from music appreciation (after all, music can be enjoyed even on the cheapest of audio players) but from affording and assembling such systems, and then showing them off to their friends.

While most sincerely believe those thousand-dollar, plutonium and powdered frankincense speaker cables made all the difference to the sound (only once they are burned-in of course), some of the best systems I've heard have been put together using decently-made individual components from yesteryear.

A good example is the Sony SA-VA15 Home Theatre system I purchased back in the mid-90s. I bought it on the same day I bought my first (and only) game console, a Sony PlayStation 1 and as I needed a decent sound system to enjoy the games I bought to play on it, this then-new Sony system was reasonably-priced and fitted the bill perfectly.

This one is a little different than most home-theatre systems as we know them today. The amplifier is built into a heavy timber and moulded-plastic tower speaker (front left) while the right-hand cabinet holds the front right speakers and a sub-woofer.

When one thinks of a sub-woofer, we usually imagine a 300mm, or more, heavyweight woofer built into an enclosure pointed towards the floor, but since there isn't that much room inside the tower-style cabinet, or a hole in the bottom of it, the subby must be a lot smaller than that. Regardless of the reduced size, it certainly does the job!

The towers are about a metre high and while mostly made from that thick, Weet-Bix-style particle board most speaker manufacturers love to use, they also have a thick, moulded plastic front with tuned audio ports exiting at the lower front face of the cabinet. The two front towers are connected via a flat, 4-metre long multicore cable.

The whole thing doesn't sound particularly appealing but it is a very well-made system and for its time also looked the part. It boasts a "virtual" centre speaker and two "rear" speakers in smaller hard plastic cabinets that

Items Covered This Month

- Repairing a Pioneer SX-950 amplifier
- Rohde & Schwarz spectrum and distortion analyser repairs

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~WITH THE WINDOW-RATTLING SUBWOOFER ENOUGH TO GET ME INTO TROUBLE WITH MY THEN-NEIGHBOURS...

connect to the appropriate speaker terminals of the amplifier via 20-metre-long twin-core cables.

If one only wants stereo, there is no need to set the rear speakers up. However, Alien Trilogy on the PS1 made good use of 5.1 surround sound and it was well worth the extra work wiring them in. Hearing a Xenomorph scream at you from somewhere in the blackness just behind your head is terrifying, and this would be a lot less effective in plain old stereo.

The amp's specs, from memory, are 100 watts/channel, with the window-rattling subwoofer being efficient enough to get me into trouble with my then-neighbours on more than one occasion.

I still have this system in my workshop and I use it for amp and audio device testing and other menial audio-related tasks. It is still an excellent system and we would still be using it as our main sound reinforcement in the house, except for the fact that it developed a faint crackle in the left-hand channel a few years back. Rather than repair it straight away, we replaced it with another more modern – and supposedly better – LG Blu-ray capable system instead, thinking we were moving forward.

I can't help but feel that aside from the later technology of the included Blu-ray player (which I have never actually used to play a Blu-ray disc), it was actually a step backwards.

A big difference I can see between the old and new systems is that the old system is designed to be repaired, with removable panels and recognisable components, whereas the LG uses many modular and proprietary components that, should one fail, are most likely difficult (if not impossible) to obtain.

I haven't tested that theory and so I might be off the mark, however experience leads me to believe this is likely the case. The one time I opened the case in an effort to find a part number on the Blu-ray/DVD player in order to find a hacked, region-free firmware for it, the actual module was like something I've never seen before or since, and I've seen a lot of those types of optical modules.

My guess is that it is a proprietary part made specifically for this (or similar) systems and this is likely why no-one had a firmware upgrade available for it. The Sony system had been assembled using what I like to call "analogue" components, that is, discrete transistors and capacitors that I can actually identify and swap out if necessary.

Hybrid output modules are used, however they are clearly labelled and readily available should one fail. Another difference between the two is that I can barely lift the Sony system's main speakers, while the spindly speaker towers on the new system could be thrown across the room by

anyone's grandma with just one hand.

Everything on it just feels tinny and somehow lacking, while the Sony has old-fashioned grunt and an innate sense of quality about it. It also sounds far better to me than the LG.

I'm not alone in this either. Over the past few months I've had several older amplifiers through the workshop to be repaired. While their owners are pragmatic in knowing they might not be repairable, they would prefer me to assess the problems and rule that option out before they go looking for what they consider 'inferior' new equipment.

They'd all spent considerable time and money back in the day setting up their ideal sound system and don't particularly want to have to go through that again.

While the market for speciality, high-end amplifiers has always been there and always will be, I am not really including that part of the market in this discussion because not many of us are prepared to shell out 10 grand plus for an amp and speakers (and cables) no matter how excellent they might sound.

I'm guessing buyers of such systems would definitely have their gear repaired before buying new again. After all, not many of us could rationalise a purchase like that once, let alone twice! I'm talking about amps made by Pioneer, Marantz, Sony, Denon, Harman/Kardon and other quality brands that made some very good gear at (relatively) affordable prices.

While some of this stuff was pricey back then, it had the quality to match and it is these amplifiers that are increasingly coming in for repair. These amps might not boast the very latest technology, but their specs are still very respectable and the hardware itself still worthy of investment to keep going.

In most cases, they are incredibly well-made, have powerful output stages, and specs that are still superior to much of the tatt they sell at big-box stores today.

Manufacturers today seem to think that the only specification that matters is output power (measured in Peak Music Power Output of course) and as far as looks go, they seem to compete for how many flashing lights and cheesy displays they can cram into their machines, not to mention speaker cabinets.

Can you imagine a set of SILICON CHIP Majestic speakers with blue and red flashing LEDs? I know, I know…

One of the amps I had into the workshop recently is a Pioneer SX-950, a behemoth of a thing that weighs so much I had to use a sack-barrow to move it and the box it came in up the driveway to the workshop.

I suppose the weight is the thing a lot of modern buyers don't like, however to my mind this denotes a certain quality, as I know it will have a decent power transformer (and correspondingly strong chassis to contain it). I was right on both counts.

After removing the timber and steel vented covers, I was struck first by the size of that transformer and again by the size of the two smoothing capacitors; both were 22,000µF 63V electrolytics and measured 50 x 110mm!

There is also a weighty flywheel for the tuner's dial cord assembly and various formed steel covers, grates and panels that all add up to heavy. It just oozes power and quality and this is precisely why the owner would rather try to have it repaired rather than simply dump it in the skip, as one would probably happily do with much of today's more cheaply-built offerings!

The problem with the amp? According to the customer, it was intermittent in switching on. That is, sometimes it would go and sometimes it wouldn't. And when I say go, I mean that the panel lights would always come on but the sound wouldn't always come out of the speakers.

After quizzing the owner more closely about the symptoms, I learned that he could tell if it wasn't going to go by the sound of the speaker/thump protection relay clicking; or not. If it gave a healthy-sounding mechanical clunk, he knew it would go. If instead it sounded weak and wheezy, he knew it wouldn't.

To resolve this, he simply switched it on and off a few times and in most instances, it would work properly after a few cycles. However, of-late, no amount of on/off cycling made a difference, so it was obviously time for an expert opinion. Since I didn't know any experts, I'd have to be the one to take a look at it!

A circuit diagram is a road map

The handiest item to have when repairing anything electronic is a circuit diagram. It's like having a road map in a strange city; with it, one can navigate around. Without it, one can still stumble around and may even find their destination, but the time wasted is non-recoverable (and mostly non-chargeable too!).

Fortunately, like many owners of proper stereo gear, the owner had all the manuals and even a fold-out circuit diagram, though I barely needed it. Tracking down the protection board was as simple as following the speaker connections back until they hit the relay's normally-open contacts. The relay sat on a socket on a PCB that also contained the circuitry that drove it.

After carefully making sure there was nothing dangerously exposed, I plugged the amplifier in and turned it on, monitoring the voltage across the relay's coil terminals. As the amp came to life, I could see the voltage rising on the coil, expecting to see the relay snap closed at around 23V; it didn't. It did half-operate, with a little chatter, but it was certainly not a definite action.

Before going further, I tried a few more times, as the owner would have done, to see if there was any difference; there wasn't. The relay just wasn't doing the business, which meant one of two things; the relay was tired and faulting, or the driver circuitry wasn't supplying enough herbs to actuate the relay.

First stop was the relay itself. It is a 24V 2A unit and, as in any quality amplifier, reaching it and removing it was a doddle. Two screws held it to the chassis and once they were removed

it easily pulled out of its socket. The clear plastic cover could also be removed by prying the base of it carefully up and away using the two clip access slots moulded into it on either side. No potted rubbish here!

Under the microscope the contacts looked to be in poor condition. This could simply be a case of the contacts wearing out but to test the theory, I dialled in 24V on my bench power supply, limited the current and touched the leads to the coil terminals. The contacts closed, but not convincingly. Repeating the test a few times told me all I needed to know. This relay was tired and needed replacing.

After a rummage through my spares, I found a similar relay and the downloaded datasheet confirmed the specs were identical, as was the pin layout. Another benefit of this type of gear; for the most part they used off-the-shelf parts, so replacements are easy to find. There's even one available on AliExpress if push came to shove.

I plugged the relay into the socket and screwed it down; I already knew it would resolve the issue and a quick power-on test confirmed it; the relay closed with an assuring clunk each time I switched the amp on and off.

Reassembling everything was the reverse of disassembly and after wiring in some proper speakers, I had a nice afternoon listening to my favourite sounds, with periodic re-starts just to make sure. Another 'proper' stereo amp was saved from the landfill.

Fixing costly gear on the cheap

A. L. S., of Turramurra, NSW, recently had two similar faults in two different, expensive pieces of test equipment. Luckily, he was able to sort them both out...

I managed to pick up a Rohde & Schwarz FSEA30 20Hz-3.5GHz spectrum analyser on eBay for a fraction of its original price, which would have been in the tens of thousands of dollars. It's an older model but still very useful and the one I bought had been calibrated recently, in 2013. It looks a bit tatty but its self-test procedure confirms it is in fully working order. A bit of a bargain, really.

The FSEA is great for audio analysis because of its displayed average noise level (DANL) of -110dBm at 1kHz and -159dBm at very low frequencies. It has a 1Hz resolution bandwidth (RBW) with a 1Hz video bandwidth (VBW) and sweeps the entire spectrum in 5ms. Not many modern analysers are able to match this performance.

The manual clearly states that the instrument retains its settings when turned off, however, this particular instrument did not. It seems like a minor fault but with an instrument of this complexity, there may be up to thirty button presses for a particular setting and having to set it up each time it was powered on was somewhat annoying!

Foraging through the Rohde & Schwarz service manual, I found a small reference to an internal lithium battery which has a lifetime of approximately five years. No reference was given for this magical battery location, nor its voltage, except for a Rohde & Schwarz part number.

Rohde & Schwarz advise in the manual that the instrument should be returned to them to replace this battery but because of the bargain basement price for the whole unit, an expensive factory repair was out of the question. I basically just resigned myself to setting the unit up from scratch each time I wanted to use it.

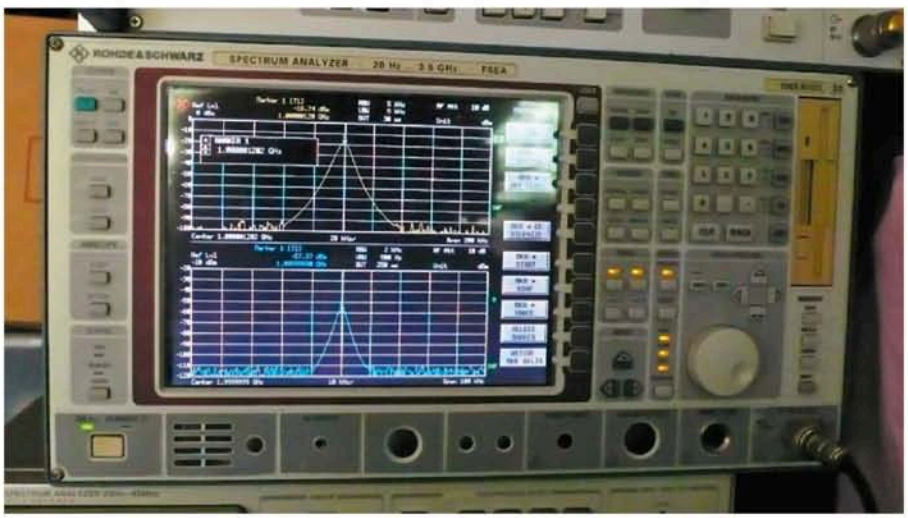
Some weeks later, though, when I switched on the instrument, I got a "ratatat" noise from the cooling fan, as if something was stuck in the fan blade. Looking into the two fan inlets with a torch, I couldn't spot anything obvious. Emergency surgery was now required to fix the fan and I figured that while the instrument was opened, the lithium battery could be easily replaced. Boy, was I wrong!

Opening everything up exposed a complex array of seven large plug-in boards, each one completely shielded in its own metal jacket and each marked according to its function. The dreaded battery was nowhere to be seen and was certainly not marked.

At least I could see the source of the fan problem. The air filter pads in front of the fans had perished and lumps of the rubberised filter had been chopped up by them. Big bits of material were floating all around the inside of the device, hiding most of the components in a pile of dusty fragments.

I found that there were, in fact, four separate fans: two for the power supply, one for the CPU and another to cool the daughter boards.

A vacuum cleaner sorted out the dust. However, this is dangerous due to the possibility of destructive static



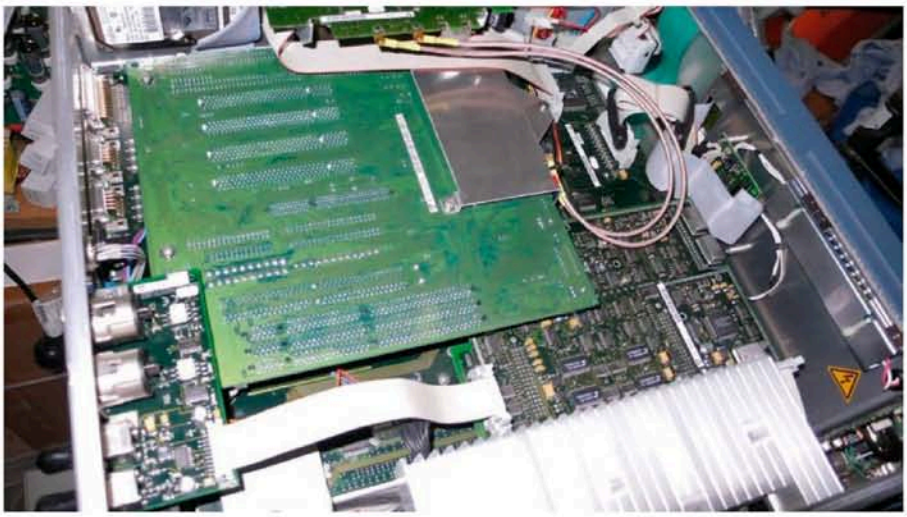
The Rohde & Schwarz FSEA30 20Hz-3.5GHz spectrum analyser sprang to life after the internal 3.6V lithium battery had been replaced.

Servicing Stories Wanted

Do you have any good servicing stories that you would like to share in The Serviceman column in SILICON CHIP? If so, why not send those stories in to us? In doesn't matter what the story is about as long as it's in some way related to the electronics or electrical industries, to computers or even to car electronics.

We pay for all contributions published but please note that your material must be original. Send your contribution by email to: editor@siliconchip.com.au

Please be sure to include your full name and address details.



Removing the power supply from the inside of the Rohde & Schwarz UPL audio analyser helped to free the other boards for removal while searching for the CMOS battery. This battery ended up being a CR2032 cell located on the underside of the large PCB in the upper left of this photograph.

discharge but because the weather was extremely wet and very humid at the time, keeping static down, I chanced it. I completely cleaned out all the fans and then began the search for the battery.

I removed the demodulation board from the rack after unscrewing a keyway to permit access to the other connections for further vacuum cleaning. All the connectors were marked and photographed because of the complexity; otherwise, I would have difficulty when it came time to reassemble it.

The battery was unlikely to be on any of the daughter boards because they provided optional features such as vector analysis, FFT and IF, with a couple of gaps for other options my unit lacks such as a tracking generator.

I went to the most obvious place, the power supply unit, which was in a completely enclosed metal box. This was removed and opened after much blood and sweat (the tears came later) revealing four exposed PCBs stacked at all different angles (like a house of cards).

Unfortunately, the nature of the battery such as its size, shape or voltage was not given in the manual but there was a component which looked like an AA-sized lithium battery.

I had to remove it to see its actual markings. It was on a separate board which took an hour to extricate! Alas, it turned out to be a weird-looking X-rated capacitor!

Reassembling the PSU required a Magician's skills but when I finally had it put back together, I noticed a rattle inside and thought: oh no! One of one of the little washers must have come loose! It had to come out to prevent a possible destructive short circuit so the whole thing had to be pulled apart again right down to the metal chassis to remove it and then reassembled for a second time, hence the tears.

So where was the battery? Searching the user manual (rather than the service manual) finally revealed the fact that the battery powered the CMOS RAM and was probably on the CPU board.

With the PSU removed, it was relatively easy to access the CPU board via a metal panel and then, deep inside (the last place I visited), there was the board with the battery. I could not have been happier if I had won Lotto.

It was a 3.6V lithium cell with pigtails, labelled "SAFT LS14250". It was the size of half a AA cell and measured zero volts.

I ordered two replacements from eBay. A Jaycar battery, Cat SB1771, is very similar and this was easily soldered in place to test everything. After reassembling the instrument, everything worked perfectly and it actually ran cooler than before.

The next culprit

I then turned my attention to another fine eBay bargain, a Rohde & Schwarz model UPL audio analyser. This was eight years old when I purchased it and it cost a fraction of the $35,000+ new price.

It was a real find because it had eight options including low distortion generators, jitter and interface tests and mobile phone acoustic testing analysis.

All test functions are available on the analog and the digital interfaces. It also analyses analog signals in the digital domain and has the ability to set up an almost infinite array of audio filters including "brick wall" filters, something that other audio analysers cannot do because they usually require a separate filter board for each filter.

Imagine my horror when some months after buying it, I switched on the UPL and it flashed up all sorts of messages such as "RAM battery low" (sound familiar?) and "hard disk is not detected" and then all sorts of gobbledygook symbols and so on!

Re-booting created even more havoc and all sorts of beeps started to sound! The battery message had disappeared so I feared that the CPU was shot!

Looking in the 'basic' UPL operating manual (462 pages long), I could find nothing on these particular messages. A UPL service manual was not to be found anywhere on the internet so I just switched it off and left it sadly sitting on the bench, hoping that a solution might be found.

I was about to think of it as a rather expensive boat anchor but because of its relatively youthful age and its complexity I decided to send it off to Rohde and Schwarz for repair. I rang them

first to see if it was repairable in Sydney but sorry – no cigar! They would have to send it off to Germany to get a quote and this would cost $1,400, including the transport.

Adding to this woe, they advised that this eight-year-old instrument was no longer supported and parts may not be available. But if parts were still in Germany, the cost of labour and repair could be up to (but not exceeding) $11,000!

I can understand Rohde & Schwarz having to charge such fees because that would only just cover their costs to employ very specialised expert engineers to fix an instrument which I would consider to be one of the most complex on Earth. But this was about four times the price I paid for it so it seemed like too much of a gamble.

I considered buying a new one but at that time, could not find any more second-hand dual domain Rohde & Schwarz UPLs at any price. I decided that perhaps I should have a go at repairing it myself. It was either that or the conversion to a boat anchor so I reluctantly decided to operate.

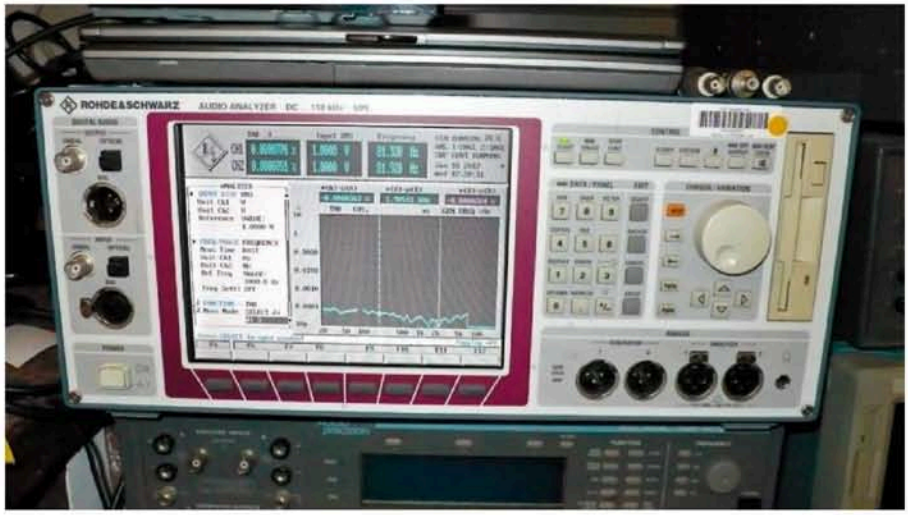
By the way, while this is a very capable instrument, the learning curve involved in operating it is rather steep. My engineer friend who worked for Rohde & Schwarz said it was designed for someone with a PhD to operate and he is not too far wrong. Was I arrogant to assume that I could fix such a complex instrument? Well, there was no other realistic option.

First, I scoured the internet but the only relevant information I could find was a small FAQ on the Rohde & Schwarz website regarding the audio analyser, entitled "hard disk not detected" where the question was "after a RAM battery change on the mainboard, the hard disk drive is not recognized anymore".

It then went on to describe a whole page of things to do: **siliconchip.com.au/link/aajy**

Since the instrument had only displayed the flat battery message once that I saw, I was not convinced that this was the problem but I went on to have a look at the battery in question anyway.

Opening the unit up, it was a puzzle just to work out where to start (see photo at upper left). Generally speaking, most complex test equipment is well-designed for performance but poorly designed for ease of service.



After replacing the CMOS battery the audio analyser was put back together and cleaned. However, it was still displaying the "hard disk not found" error message. Pressing the Page Up key on the machine booted into the BIOS and the correct settings could then be entered, allowing it to start properly.

As with the FSEA spectrum analyser repair, the RAM battery was nowhere to be seen. In fact, it was not even obvious which was the "mainboard" that Rohde & Schwarz had referred to.

The technique I used was to photograph all the boards and connectors then take the boards out one at a time. There appeared to be an order to disassembly but I was working without any information at all and even removed the hard disk drive, hoping that the mainboard would be beneath it. But that turned out to be incorrect.

I removed the power supply and this seemed to be the key to releasing the other boards. I then came to a slightly larger board which had upwards-facing components. This had microscopic tracks, thousands of them, and I had to admire the exceptional engineering which had gone into it.

Unfortunately, the component side was still mostly blocked by other bits so I couldn't see if the battery was there or not. I had to remove it and this took a fair bit of time.

Finally, I was able to turn it over and there it was: a 2032 lithium button cell inserted into a battery holder! This was certainly unusual because all of the batteries I have replaced before in both HP/Agilent and Rohde & Schwarz instruments were solder types with either pigtails or PC pins.

The cell measured 2.5V and replacing it took mere seconds. I then put everything back together, but took the opportunity to clean dust off all the boards and cleaned all the connectors with aerosol. I also took the opportunity to inspect the other components, in case there was another fault.

After a couple of attempts, it all went back together and I screwed the cover on and fired the thing up. The same "hard disk not found" message popped up so I immediately grabbed the printed FAQ instructions to try and get it going.

I did all this but they failed to mention what keys were needed to display the required settings. After hitting just about every key I could think of, "Page Up" finally did the job and I could proceed. Apparently, the hard disk drive is not connected to the mainboard but to the digital board, so you have to select the "Standard CMOS SETUP" folder and set the primary master as shown in this link: **siliconchip.com.au/link/aajy**

The whole setup process took me a good hour but on restart, it still didn't work. I ended up going through the process three more times before I got everything looking as per the FAQ.

Then, bingo. The instrument sprung to life! I gave out a huge roar of "yes, yes, yes" and jumped up and down with sheer joy it was so satisfying to be triumphant over a machine and save $11,000.

Also, all the options worked correctly and no permanent damage was noted. The instrument has performed without a glitch but I have kept the instructions with it because 2032 cells don't last long. But at least I can get them at the supermarket. SC

Building our all-new 800W plus!

Part 2:
by Duraid Madina
and Tim Blythman

Uninterruptible Power Supply

Keep mains-powered equipment running during blackouts with this high-power, high-capacity Uninterruptible Power Supply. It uses modern lithium-iron-phosphate batteries which will withstand being repeatedly discharged without damage. This makes it considerably lighter and more compact than most equivalent commercial UPSes.

Last month, we described the overall concept of our new $LiFePO_4$-powered UPS and explained how it was designed. We also provided a list of parts needed to build it, including information on where to get them.

In this article, we provide a list of the parts you need to build the control shield, explain how the shield works and how to assemble it.

We'll then go through the steps required to prepare the case, mount all the parts and wire them up. It's a fairly elaborate unit which includes high-voltage and high-current wiring, so take your time and make sure you follow all the instructions carefully to ensure that you build it safely and so that it works first time.

Control circuit description

The circuit details for the Arduino control shield are shown in Fig.2. So that you can see how it fits into the overall scheme, we've also reproduced the block diagram (Fig.1) from the first article, which incorporates the corrected wiring for relay RLY3.

The relay driver shield plugs into the Arduino board and is connected via four pins: V_{in} (the 12V supply), ground and two I^2C bus control lines, SDA (data) and SCL (clock). The Arduino sends commands over the I^2C bus to set the state of the eight relay driver outputs. Six are used, three to drive the mains switching relays and three for indicator LEDs.

The control shield is stacked on top of the relay driver shield and contains the additional circuitry shown in Fig.2.

These components allow it to monitor the inverter's state, the shape and voltage of the mains waveform and the battery voltage. They also let it switch the inverter on and off, "bootstrap" itself to power up with (automatically) or without (manually) the mains supply present and sound an audible alarm to indicate the loss of mains power or low battery voltage.

Monitoring the mains waveform

The centre-tapped secondary of a 12.6V mains transformer is wired to CON1. The 6.3V tap is connected to analog input pin A1 of the Arduino via a 75kΩ resistor. This forms a voltage divider in combination with the two 10kΩ DC bias resistors, to keep the voltage at this pin within the range of 0-5V.

The transformer secondary voltages will be higher than 6.3VAC because it is lightly loaded and since the mains voltage can go above 230VAC; perhaps to as high as 250VAC or more.

A 6.3VAC sine waveform has peak voltages of ±8.9V but if the mains volt-

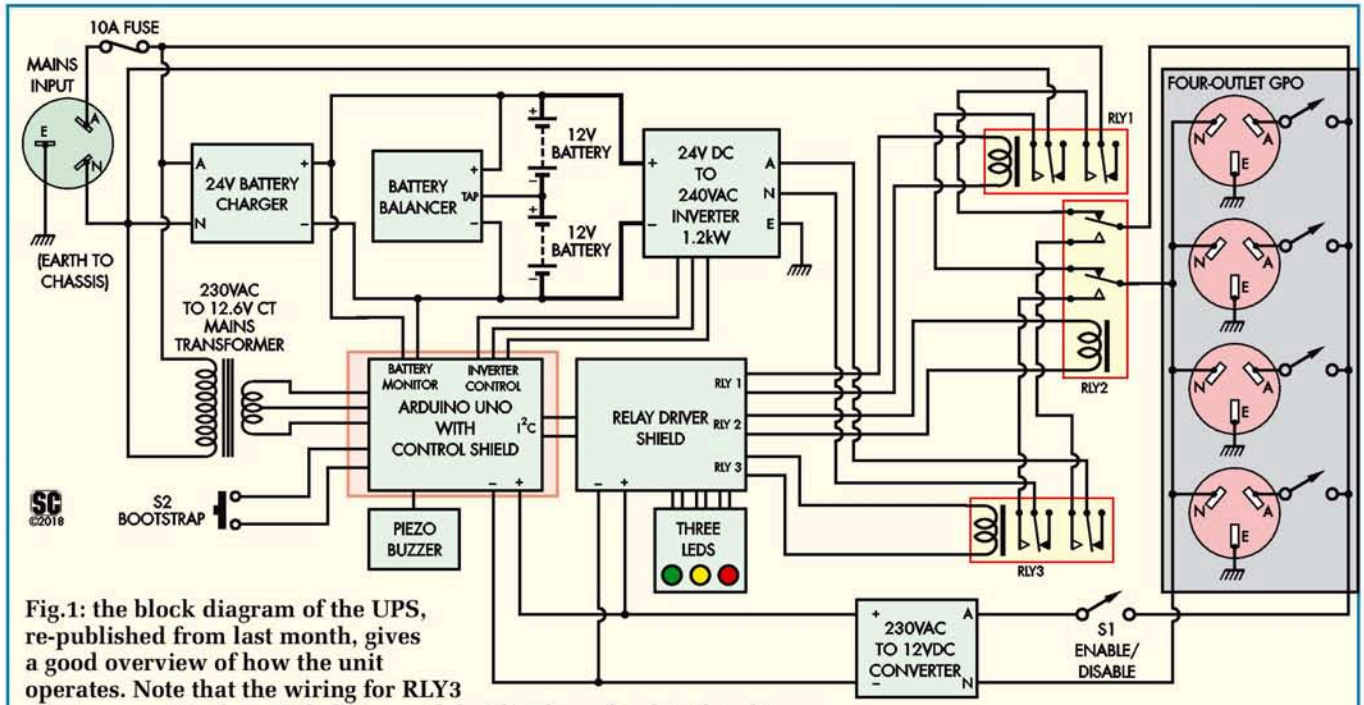


Fig.1: the block diagram of the UPS, re-published from last month, gives a good overview of how the unit operates. Note that the wiring for RLY3 was incorrect in the article last month but has been fixed in this diagram. The circuit of the Arduino control shield (highlighted at centre left) is shown in Fig.2, overleaf.

age goes to 250VAC (as it can in areas with lots of domestic solar installations) we expect it could be as much as ±10.76V at the centre tap of the transformer.

The three resistors between the transformer and input A1 translate this ±10.76V swing to 2.5V ±1.43V, (ie, about 1.07-3.93V), to suit the Arduino's internal analog-to-digital converter (ADC). This allows it to monitor the mains voltage in real-time.

The full 12.6VAC (~20V peak) output of the transformer is also fed through one of relay RLY4's normally-closed set of contacts to schottky diode D1 and into a 1000µF filter capacitor. If the Arduino is not powered but mains is present, this capacitor will charge up to around 20V.

This then feeds the input of REG1, a 12V linear regulator, to power the circuit. Once the software has determined that the mains waveform is normal and has switched the UPS output on, this is no longer necessary as the unit is powered from the 12V switchmode supply.

So the Arduino drives its D8 output pin high, energising relay RLY4. This disconnects the transformer secondary from D2 while leaving its centre tap connected to analog input A1. Diode D1 prevents the back-EMF from RLY4's coil from damaging the Arduino when it powers off and the relay is de-energised.

Diode D3 isolates the output of REG1 from the output of the 230VAC to 12V DC switchmode supply, so that when that supply powers up, it doesn't interfere with the operation of REG1 and vice versa.

This also means that the VIN rail will be a bit lower (around 11.3V) when REG1 is providing power. This can be sensed by the Arduino via a 100kΩ/10kΩ resistive divider at analog input A3.

This divider reduces the VIN voltage by a factor of 11 so the A3 pin will normally be around 1.09V when running from the switchmode supply and about 1.03V when running off REG1.

So if you switch S1 off, the Arduino can sense the voltage drop at VIN. It will then perform a clean shut-down, sequencing the relays to turn the UPS output off cleanly.

Inverter interface

The telephone-style control cable supplied with the inverter plugs into CON4 (RJ14; 6P4C). Its control lines are not ground-referenced so it is necessary to optically isolate it using two PC817 optocouplers, OPTO1 and OPTO2.

When the inverter is operating, the voltage at the green wire (pin 4) goes low compared to the common black wire connection at pin 2. This causes current to flow through the internal LED of OPTO1 and the 10kΩ current-limiting series resistor, pulling digital input D4 of the Arduino low.

It's normally held high by a current source within the microcontroller. The Arduino software can therefore sense the state of this pin to determine whether the inverter is powered up.

To switch the inverter on or off, the Arduino drives digital output pin D2 high for around 500ms. About 18mA then flows through the internal LED in OPTO2, limited by the 220Ω series resistor. This switches on the output transistor, pulling up the voltage at pin 3 of CON4 (the red wire).

This is equivalent to pressing the button on the supplied remote control unit and if the battery voltage is sufficient, the inverter will switch on. If it's already on, it will switch off. The Arduino can check the state of the D4 input pin to verify that it has done so.

Battery monitoring and switch-on

The 24V (nominal) battery is wired to CON2 and its voltage is divided down by a factor of 11 by the 100kΩ/10kΩ resistors. With the maximum battery voltage of 29.2V, this gives 2.65V at the Arduino analog input A2.

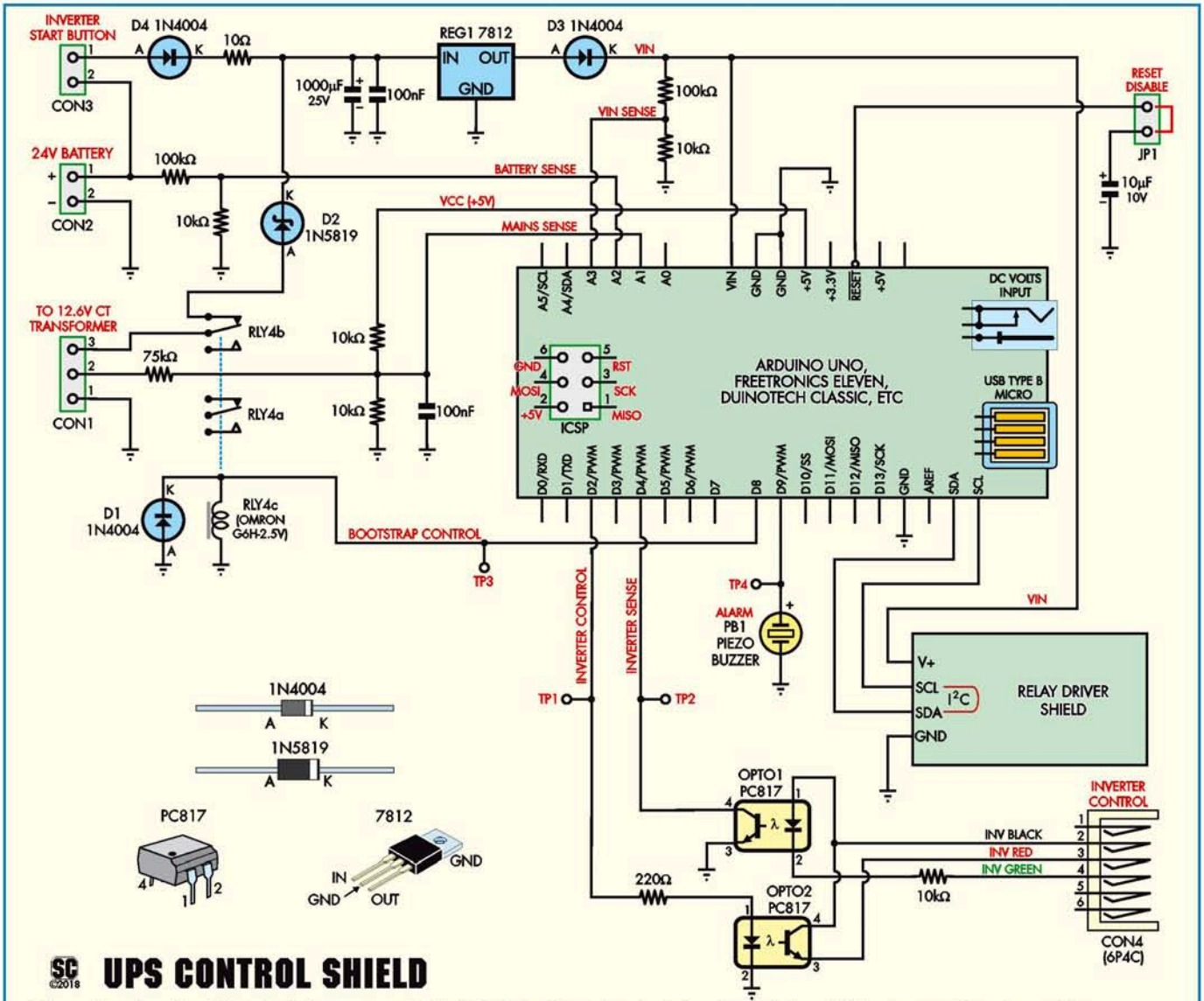


Fig.2: the circuit of the Arduino control shield. This gives the Arduino board the ability to monitor the mains waveform (via CON1 and the external transformer), control the inverter (via CON4 and OPTO1/2) and "bootstrap" the power supply after a long blackout or when the unit is being used away from mains power.

The Arduino uses this voltage to display warnings to the user via the front panel LEDs and piezo buzzer PB1. If the battery voltage gets too low, it will shut down the inverter and this will also cause the Arduino to power down.

If you manually shut it down via S1 but the batteries are still charged, you can power it up by holding down the momentary pushbutton switch on the front panel (S2).

This connects the terminals of CON3, feeding 24V to the anode of diode D4, which then charges up the 1000µF capacitor at the input of REG1.

REG1 then powers up the Arduino using the same procedure as described above. But since the mains waveform is not present, it will switch the output over to the inverter which then powers the 230VAC to 12V DC switchmode supply once the pushbutton is released.

You need to hold down this button for a few seconds to allow this procedure to complete.

The 10Ω 1W series resistor reduces the inrush current when charging up the 1000µF capacitor and also reduces the dissipation in REG1 during the start-up period.

Additional components

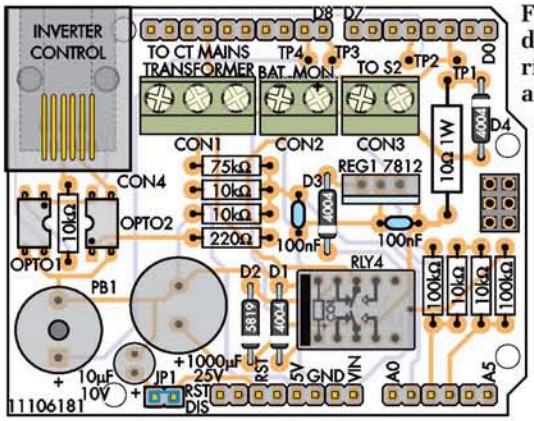
A two-pin header labelled JP1 ("RST DIS.") can be used to connect a 10µF capacitor between the Arduino's RESET-bar pin and ground. If this jumper is fitted, it will block reset pulses from the USB interface, preventing the Arduino from rebooting when it's plugged into a computer.

This allows a computer to get information about the UPS state via USB without interfering with the operation of the UPS. The Arduino can still be manually reset for uploading a new sketch by pressing the reset button or by temporarily removing the shunt from JP1.

We'll have more details in the third article next month on how standard UPS software can be used to get information from the UPS over a USB interface, allowing you to monitor the battery state and even shut the computer down before the battery goes flat.

Shield construction

Use the PCB overlay diagram, Fig.3, as a guide during construction. The



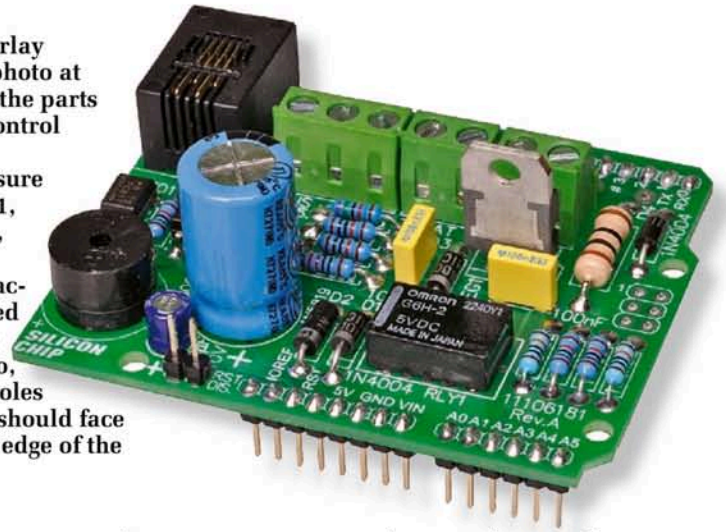


Fig.3: the PCB overlay diagram and the photo at right show where the parts are fitted on the control shield. Be careful to ensure that RLY4, REG1, OPTO1, OPTO2, the diodes and electrolytic capacitors are mounted with the correct orientation. Also, the wire entry holes of CON1-CON3 should face towards the top edge of the PCB.

shield is built on a double-sided PCB, coded 11106181 and measuring 68.5 x 54mm. It's available from the SILICON CHIP Online Shop. Start by fitting the resistors. It's best to check the value of each using a DMM before soldering them in place.

Next, fit the four diodes, ensuring that the cathode stripes are orientated as shown. D2 is a 1N5819 while the other three are 1N4004s. Then install the two optocouplers. They are the same type but have a different orientation; ensure the pin 1 markings are located as shown in Fig.3.

Follow with the three terminal blocks, ensuring their wire entry holes are facing the adjacent edge of the PCB before soldering the pins. Then move on to the small relay, RLY4. It will have a stripe at the pin 1 end and this must go towards the left side of the PCB, as shown in Fig.3.

The piezo buzzer can be fitted next, with its positive terminal towards the bottom of the PCB. Then solder the two 100nF capacitors in place, followed by CON1 and the two larger capacitors. REG1 is mounted next, with its metal tab orientated as shown.

Finally, solder the four pin headers in place where shown. These are inserted from the bottom side of the PCB and soldered to the top.

You may find it easier to plug the headers into the Arduino, flip it over and solder them to the shield board, as this will keep them straight during the soldering process. That completes assembly of the shield board.

Locating the components in the case

The UPS has a number of fairly large components and some of them get quite warm during operation. The specified case has plenty of room for the components to fit and lots of ventilation for cooling air to circulate. Note that a bigger case would be necessary if you are going to use larger batteries or more than two.

We spent quite a bit of time planning the layout of the UPS so we suggest you use the same layout. If you vary the layout, keep in mind that you should keep the 230VAC mains wiring away from any low-voltage wiring, as we have done.

Since almost all suitable cases would be made of metal, all panels must be solidly earthed. You will also need to ensure that there is adequate venting and space around the components to handle the expected heat dissipation.

One of the advantages of the case we are using is that the rear panel can be pivoted on the bottom pair of screws and folded down by removing the top two screws. This makes assembly considerably easier.

Case assembly

You don't need any special tools; a standard assortment of screwdrivers and pliers is sufficient.

You will need a decent drill and 3mm, 4mm and 5mm bits. A drill press is helpful but not required. There are a couple of larger holes which will need

Parts list – UPS control shield

1 double-sided PCB, 68.5 x 54mm [SILICON CHIP code 11106181]
1 set of pin headers (1x6 pin, 2x8 pin, 1x10 pin)
1 3-way mini terminal block, 5.08mm pitch (CON1)
2 2-way mini terminal blocks, 5.08mm pitch (CON2, CON3)
1 6P4C PCB-mount socket (CON4) [Altronics P1442]
1 DPDT DIL telecom relay, 5V DC coil (RLY4) [Omron G6H-2 5V or equivalent]
1 5V self-oscillating piezo sounder (PB1)

Semiconductors
2 PC817 optocouplers (OPTO1,OPTO2)
1 7812 linear 12V regulator, TO-220 (REG1)
3 1N4004 1A 400V diodes (D1,D3,D4)
1 1N5819 1A 40V schottky diode (D2)

Capacitors
1 1000µF 25V electrolytic
1 10µF 10V electrolytic
2 100nF ceramic or MKT *(code 0.1µF, 104 or 100n)*

Resistors (all 0.25W, 1% metal film unless otherwise stated)

	4-band code	5-band code
2 100kΩ	*(brown black yellow black*	*brown black black orange brown)*
1 75kΩ	*(violet green orange black*	*violet green black red brown)*
5 10kΩ	*(brown black orange black*	*brown black black red brown)*
1 220Ω	*(red red brown black*	*red red black black brown)*

1 10Ω 1W 5% carbon *(brown black black gold)*

CAUTION! This project involves mains voltages which can be dangerous if not handled correctly. Always be careful when dealing with this level of voltage. THIS IS NOT A PROJECT FOR ANYONE NOT EXPERIENCED WITH MAINS DEVICES.

to be made with a hole saw, stepped drill or tapered reamer.

You will also need a needle file to create the correct profile for some of the component mounting holes. It will also come in handy to even out any rough edges left after drilling. And you will need access to a vice and some large pliers to bend a few of the pieces into the required shape.

Start by putting the case together using the supplied instructions. It is sold in three parts: one includes the front, back and sides while the lid and base are sold separately.

We found it easier to fit the sides to the base with the included self-tapping screws, followed by the front and back, which are attached with bolts and nut swhich include integrated shake-proof washers.

Having assembled the bottom, front, rear and sides, we found that the lid would not fit until we loosened the front panel nuts. Once you're happy with how all the case parts fit together, remove the lid.

Next, lay out the components in the case, using our photos and Fig.4 as a guide. Remember to allow space for wiring up the components.

The inverter, Arduino assembly, battery balancer, mains transformer and relays all have their own mounting holes and so are easily attached to the base using machine screws and nuts.

The batteries have no mounting provisions so we secured them in place using six brackets placed around their periphery, bolted to the bottom of the case. We then fitted large straps over the top so that they cannot lift off the base. These are held down with long bolts and nuts.

You will need to ensure there is enough space around the batteries for the brackets to be mounted. In our prototype, the brackets are almost, but not quite, touching the sides of the case.

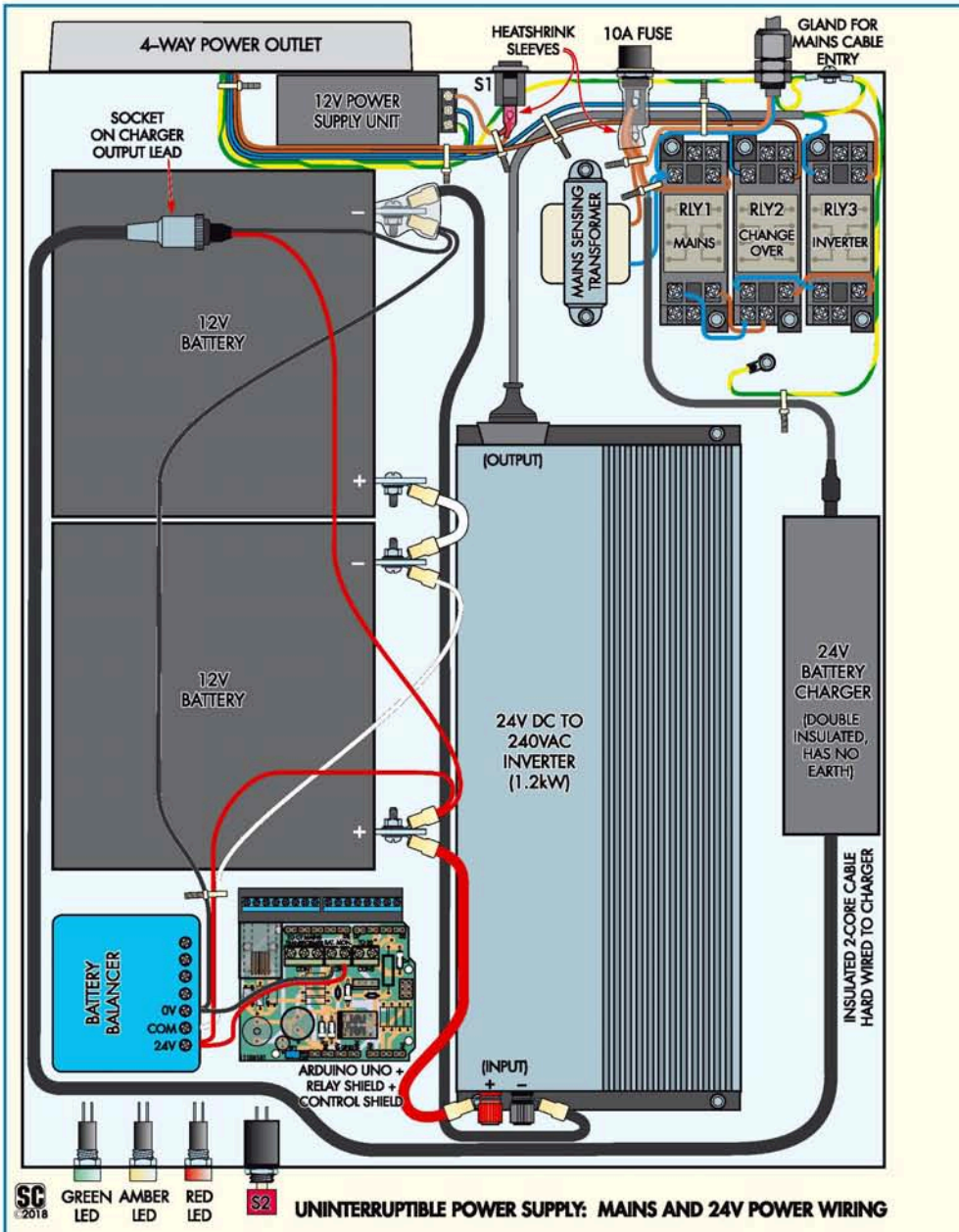


Fig.4: this shows the placement of the components in the UPS case and both the mains and 24V DC supply wiring. All wiring, but especially the mains connections, should be cable tied together and anchored to prevent movement. The mains wiring should also be kept as short as practical and insulated with heatshrink tubing where possible.

Drilling the mounting holes

With everything laid out comfortably, mark out the required location of the mounting holes for each component in the bottom of the case, using a permanent marker. Holes will be drilled in these locations later. It's also a good idea to mark out the outlines of the components, to assist with picturing the layout as it progresses.

In the case of the top plates for the batteries, the outlines make it easy to mark out the mounting holes, after removing the batteries. Once all the holes have been marked out, we suggest that you detach the base from the rest of the case as this makes drilling easier.

Now is also the time to mark out the locations to drill holes for attaching the feet. Make sure they won't interfere with mounting any of the other components. We ended up sharing a single mounting screw between one of the feet and one of the relay bases but you may prefer to move them slightly apart to avoid this.

All holes are 3mm except those for the battery brackets (5mm) and a single 4mm hole for the panel earth. The earth mounting hole is placed between the inverter and relays, near the rear panel; its exact placement is not critical.

Drill all of the holes in the base before mounting anything and ensure they have been cleaned of any swarf before proceeding.

A larger drill bit, rotated by hand

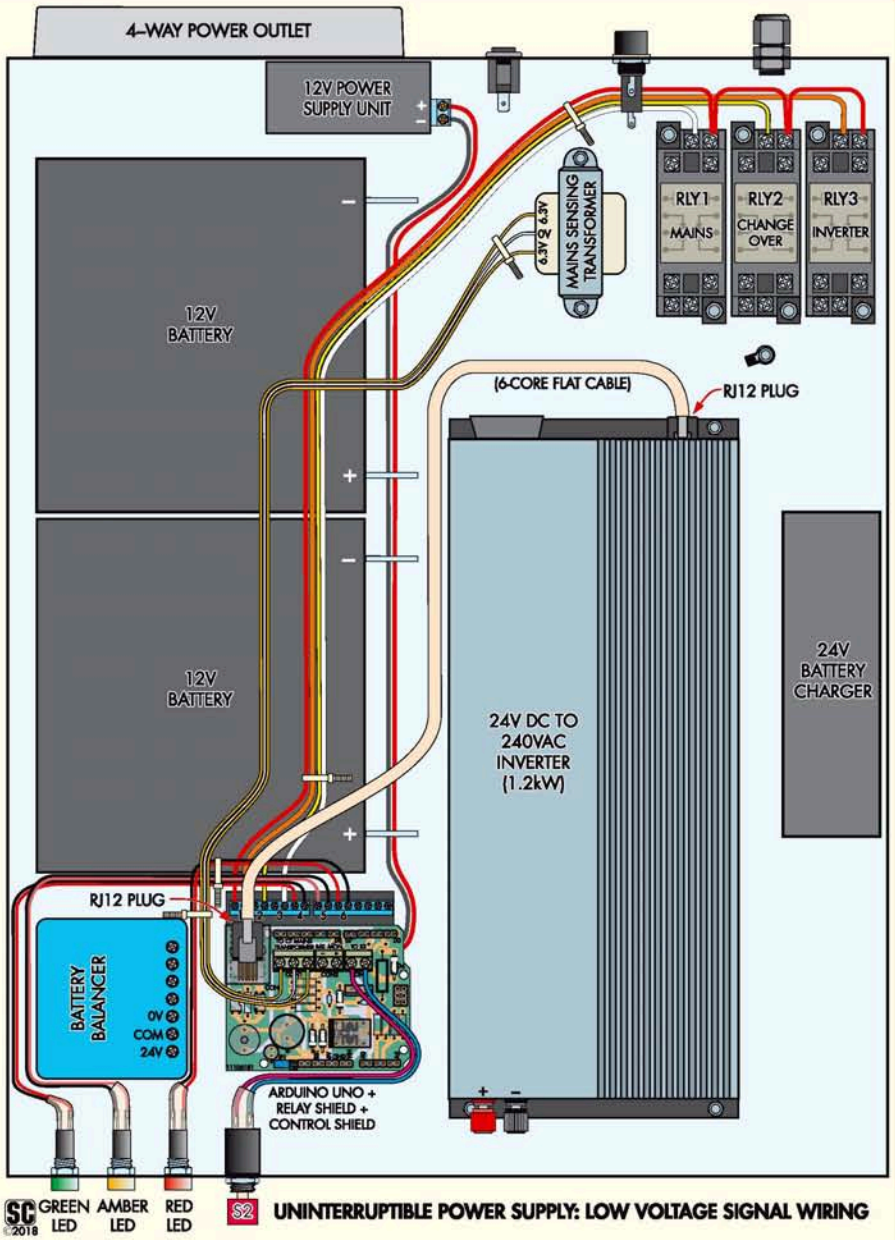


Fig.5: use this diagram as a guide for connecting and routing the low-voltage, low-current wiring. It's easiest to make the relay coil connections before completing the mains wiring (see text) and bundle up each set of cables using cable ties or tubing to keep everything neat.

in the hole, is very handy for removing swarf.

Fitting the components

Re-check that the holes are in the correct positions to suit all the components before you start mounting them. The order of assembly is not critical but there are a few things which make the process easier.

Leave the batteries and inverter until last as they are the heaviest items.

For each component, insert screws from the underside of the panel and fit nuts and lockwashers on the inside of the case.

If you have an L-shaped bench, you can position the case across the two edges so that you can access the underside to do up screws while its weight is supported. Be careful to ensure it is stable before proceeding, though.

Start by mounting the relay bases using M3 x 15mm machine screws with a nut and washer on each. Mount them with the round hole in the top surface closer to the rear panel. Leave the relays off for now.

The transformer is next and only needs two M3 x 10mm machine screws. Orientate the transformer with the primary (blue and brown wires) facing towards the relays and the secondary (white and yellow wires) facing away. This will help to keep the mains and low voltage wiring separate.

The balancer is another simple item to mount, needing four M3 x 10mm machine screws with nuts and lockwashers.

If you are using our Battery Balancer from last month's issue instead, you could mount the PCB to a piece of PCB prototyping board such as Jaycar's HP9556 or Altronics' H0701 by soldering some short stiff wires between the two. This can then be mounted to the case using the holes provided in the prototyping board and some tapped spacers.

To lift the Arduino Uno up so it was more accessible (especially the USB socket), we used a number of tapped and untapped spacers and long screws.

Start by threading 25mm Nylon machine screws through the holes in the Arduino and into pairs of 15mm-long Nylon tapped spacers on top of each other. The use of Nylon is important, to avoid accidental short circuits.

We had to trim the head of the machine screw nearest the SCL pin due to low clearances on the board. In this case, the tapped spacer needed to be threaded onto the machine screw, as the machine screw will not be able to rotate.

Now feed M3 x 32mm machine screws up through the holes in the panel underneath, place 25mm untapped spacers over their shafts and screw them into the tapped spacers already attached to the underside of the Uno.

You can now plug the relay driver shield into the Arduino and then plug the control shield that you built earlier into the sockets on the top of that.

Next, mount the inverter using four M3 x 10mm machine screws, nuts and lockwashers.

Finally, we come to the batteries. We started by mounting the six angle brackets using M5 x 10mm machine screws, M5 nuts and lockwashers, ensuring that the batteries are a snug fit and cannot move around (see photo on page 72).

Next, feed the eight M5 x 90mm

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machine screws through the base and attach one M5 nut to each, holding them steady. This is important as otherwise, you risk contact with the battery terminals which could possibly short them out once the wiring is in place.

Test fit the batteries and flat plates to ensure that everything lines up and then clamp the plates down on top of the batteries using another eight M5 nuts and lockwashers. It should look like the photo on page 72.

Having determined that everything fits, remove the plates for now, giving better access to the battery terminals.

We mounted the charger on the side panel to save space. It's prevented from moving forward and back by screws through the side panel (the holes just happen to be spaced perfectly for this) and in the other dimensions by a metal clamp which we have fitted over the top and bent to provide plenty of friction (see photos on pages 72 & 73).

This clamp is made by cutting a 15cm length of Carinya 20 x 200 x 1mm Flat Make-a-Bracket (Bunnings Cat 3975816).

This was not included in the parts list last month but you could just as easily use a 20mm x 150mm strip of aluminium or thin steel plate with a couple of 3mm holes drilled in it.

Bend it into a "Z" shape in a vice so that when one section is attached to the side of the case, the other two sections clamp the charger in place. Attach it via the existing side panel holes using two short 3mm machine screws, lockwashers and nuts.

Front and rear panel preparation

Re-assemble the enclosure to double-check that everything fits properly. Then remove the back panel. Unclip the front from the four-outlet GPO to reveal its six mounting holes and mark out the hole positions on the rear panel.

To save space, we mounted the 12V switchmode power supply directly behind it. To do this, you need to drill the six mounting holes for the GPO, then measure the distance between the mounting holes on the PSU and locate them relative to the existing GPO mounting hole.

The shared screw is the one which goes into the GPO mounting location just to the right of the left-most outlet. You need to use a 6mm machine screw here; the other GPO mounting screws are 10mm and have nuts and lockwashers on the back.

Having prepared the GPO and PSU mounting holes, you now need to make a large hole for the central protruding part of the GPO to fit through (ie, where the wiring is attached). You will also need to drill holes for the mains input lead/cable gland, fuse holder, on/off rocker switch and a 4mm hole for the rear panel earth bolt.

We chose to space the switch, fuse holder and mains cable gland out evenly along the centre-line of the panel. Ideally, the earth bolt hole should be located between the mains input lead and fuse holder.

The hole for the GPO protrusion is the largest and its size is not particularly critical, as long as it's large enough and doesn't extend outside the GPO outline.

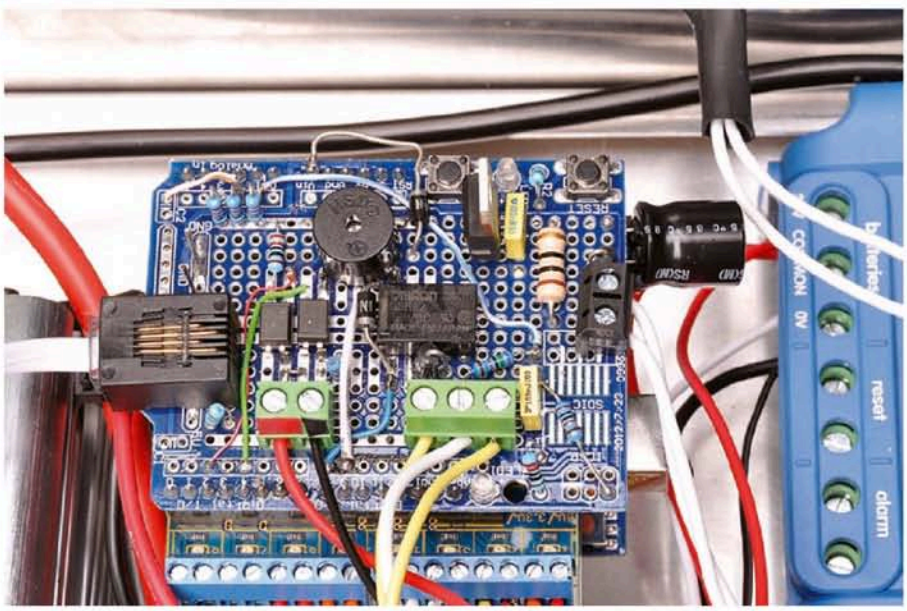
We made it by drilling a number of 6mm holes around the perimeter of the opening, then nibbled and filed away the remaining material until we could knock out the central panel.

Test-fit the GPO and make sure the locations where the Active and Neutral wires are terminated are not too close to the edges of the hole.

Because the switch, fuse holder and mains cable entry holes need to be more precise, drill a pilot hole for each and then opened them up to as large as possible with drill bits, followed by careful use of a tapered reamer to get them to their final dimensions. Test fit along the way to ensure the holes don't get too large.

Make sure to clean away any swarf or sharp edges with a file and use the same file to cut a slot to allow the tab on the switch to fit through the panel.

You can now mount the components on the rear panel, starting with the switchmode power supply on the



Detail of the control shield installed. This prototype version is electrically indentical to the PCB described earlier in this article.

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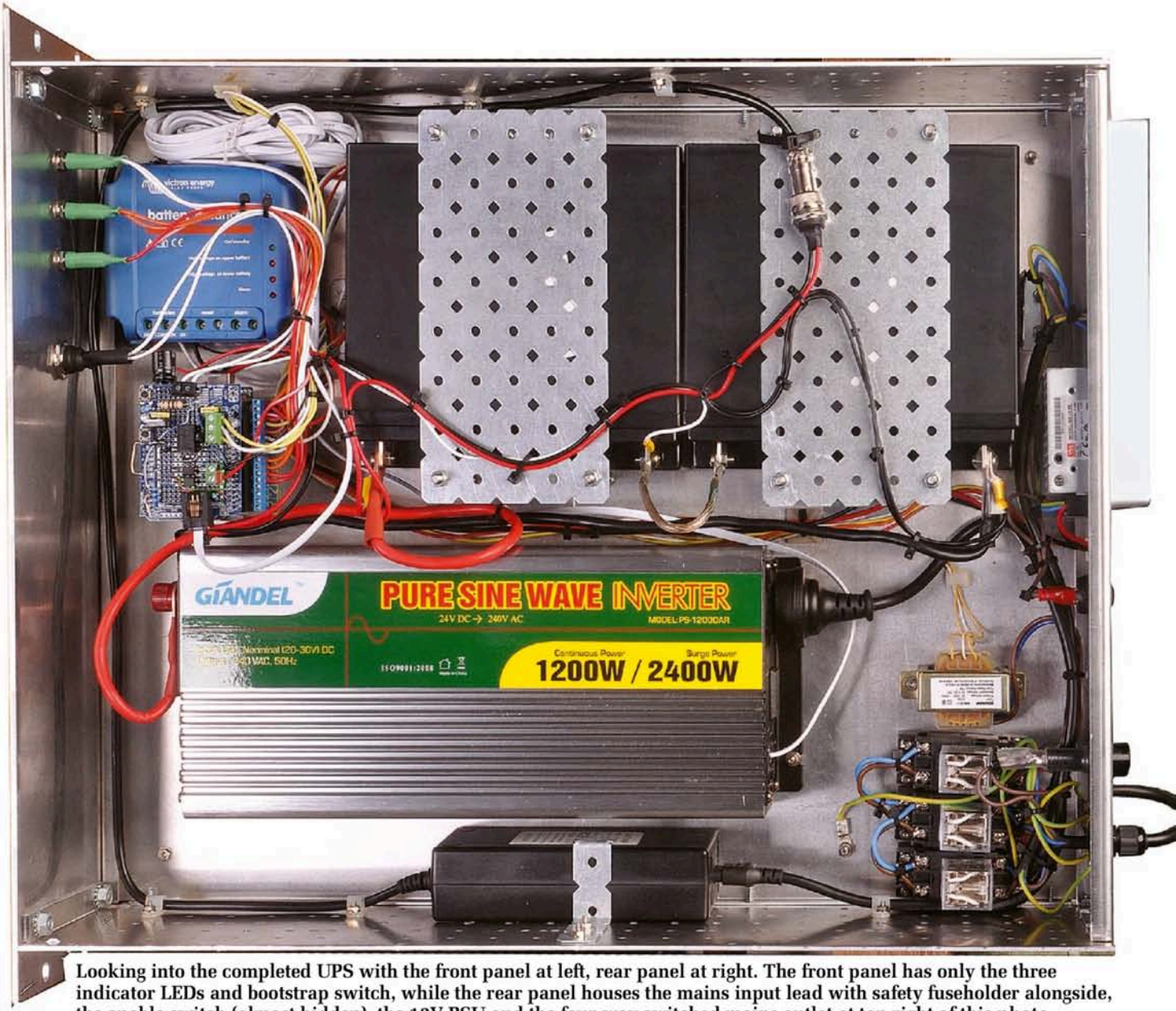


Looking into the completed UPS with the front panel at left, rear panel at right. The front panel has only the three indicator LEDs and bootstrap switch, while the rear panel houses the mains input lead with safety fuseholder alongside, the enable switch (almost hidden). the 12V PSU and the four-way switched mains outlet at top right of this photo.

inside, which is attached using 6mm M3 machine screws into its tapped holes. Remove the screw which is shared with the GPO, then mount the GPO using a 6mm screw in the shared position and 10mm screws, nuts and washers for the other five.

The rocker switch is a snap fit while the fuseholder attaches by means of the included nut and washer, as does the cable gland for mains entry.

Now remove the front panel and marked it out to suit the three LED indicators and the momentary pushbutton. Given that there is even more space on the front panel, this is not so critical, so again we aimed for placing these items evenly along the front centreline.

We drilled the holes to suit (6mm for the LED indicators and 13mm for the pushbutton) and test mounted all the items before removing them again. Given that we will have to solder wires to them, and the front panel does not have a convenient fold-down feature, it is much easier to remove them at this stage.

When positioning these holes, keep in mind that they need to be inside the locations where the side panels meet the front panel.

Wiring it up

There is a lot of wiring in this project, including 250VAC-rated mains wiring, high-current 24V DC wiring and also low-current, low-voltage wiring.

Take care to ensure that the mains-potential wires are kept away from the others and that they are not needlessly long and free to move about.

Once fitted, the 3-pin mains plug MUST be removed any time you are working on the UPS.

But you shouldn't be too careless with the batteries either as they can deliver in excess of 100A when shorted. So be very careful when making or changing any wiring to the batteries.

Keep in mind that the inverter output is also a high-voltage risk and it can be powered up even when the unit is disconnected from mains!

Battery wiring

The battery wiring is a good place to start and the details are shown in Fig.4. Use electrical tape to insulate the bare ends of wires while doing this, to avoid accidental short circuits. Be careful to avoid shorts while doing

this wiring since the batteries can supply a lot of current.

There are three buses that connect to the batteries. These are:

- The 0V bus, which connects the battery negative terminal to the charger, balancer and inverter negative terminals and the Arduino ground (black wires).
- The 12V bus, which joins the two batteries and also connects to the balancer (white wires).
- The 24V bus, which connects the battery positive terminal to the charger, balancer and inverter positive terminals and the Arduino 24V input (red wires).

The inverter is supplied with thick red and black leads with eyelets at each end. We used these to connect the batteries to the inverter inputs and made up wires for the remaining connections. Use 10mm M4 machine screws, shakeproof washers and nuts to attach the leads to the battery terminals.

Our charger came with quite a lengthy output lead, as depicted in Fig.4, so we only had to solder short lengths of wire to a matching socket to connect to the batteries.

You will need longer wires if your charger lead is shorter.

To complete the 0V bus, we need to connect the charger, balancer and Arduino to the battery 0V terminal.

The charger wiring will carry several amps while the other connections are well under 1A but you can use medium-duty or heavy-duty hookup wire for all these connections.

We used a 40cm length of black wire from the battery to the charger connection and a 100cm length from the battery to the balancer.

These were both crimped into a single 4mm eyelet. Attach this eyelet with the same screw that's holding the inverter cable onto the battery negative terminal.

While making this connection, slip a 50mm length of 20mm diameter heatshrink tubing (ideally, clear or black) over the whole assembly – both eyelets, the battery terminal and the screw.

This should cover all the exposed metal and later, when we shrink it down, it will prevent any stray wires from contacting this terminal.

Solder the shorter black wire onto the charger socket negative terminal and screw the longer one into the battery balancer negative terminal, along with a second 30cm length of black wire which is then attached to the BAT - terminal on the Arduino shield.

Similarly, for the battery positive connections, cut a 60cm length of medium-duty red wire (for the charger) and a 30cm length of medium-duty red wire (for the balancer) and crimp these into a single 4mm eyelet.

This is attached to the battery positive terminal using another M4 machine screw, nut and shakeproof washer.

Solder the longer wire to the positive terminal on the charger socket and screw the shorter wire into the positive terminal of the battery balancer, along with a 30cm length of red medium-duty wire, which you can then connect to the BAT + terminal on the Arduino shield.

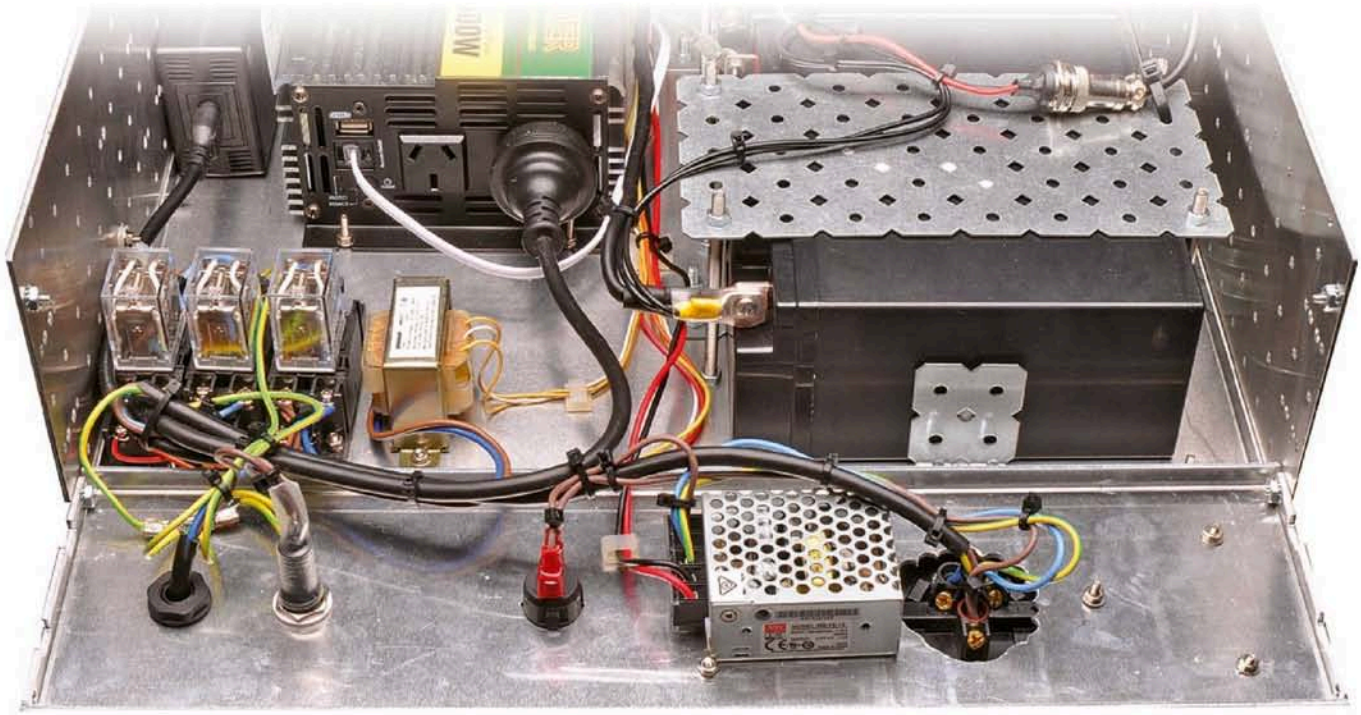
This connection should have no effect until the pushbutton is wired up later.

The link between the two batteries is made from a short length of very heavy-duty wire with a large 4mm eyelet crimped onto each end.

We suggest you use a vice to crimp these (unless you have a special tool) since these will carry the full battery current (30A+) and the connections need to be good!

Then we just need to run a wire from one of the two joined battery terminals to the centre tap on the balancer. Crimp a 40cm length of white light or medium-duty wire into a 4mm eyelet and attach this to one end of the heavy inter-battery cable, then screw the other end to the COM (common) terminal of the balancer.

Before proceeding, ensure that the



We've "folded down" the rear panel in this photo to show its contents clearly: from left, the mains input lead, 10A safety fuseholder, the enable switch, the 12V PSU and the four-way switched mains outlet. Note the liberal use of heatshrink sleeving.

screws holding the terminals onto the batteries are all very tight, along with the inverter input terminals.

All the battery terminal connections need to be done up tight or they could overheat when the unit is operating due to a high resistance.

Mains wiring

You need two mains leads with moulded plugs. These are for the incoming mains connection and the output of the inverter. They can be cut from spare equipment power cables or purchased separately.

The incoming mains lead should be at least one metre long, as this will need to reach a nearby GPO. The mains cord needs to be held securely with the cable gland so it cannot be pulled out.

Additionally, the securing nut on the gland should be locked using super glue around the thread before tightening to prevent its being easily removed.

The inverter lead should be around 50cm long and does not exit the case.

Note that all the wires used for Active, Neutral and Earth should either be stripped from mains cords or mains flex or **be rated for a minimum of 250VAC at 10A or more**.

They **must** be colour coded correctly: brown for Active, blue for Neutral and yellow/green striped for Earth. The correct colours are shown in Fig.4.

The three relays (left to right) are for mains switching (RLY1), output changeover (RLY2) and inverter switching (RLY3).

This keeps the wiring as short and neat as possible.

The wiring from each relay to the incoming mains, inverter and output GPOs all attaches to the relay bases close to the rear panel.

The connections on the other side are between adjacent relays only and as you can see from the photos and diagrams, are fairly simple.

Keep these wires short (around 10cm) and cable tie them together once they have been finalised.

Make sure to do the screw terminals up nice and tight so they won't come loose.

These short wires can be stripped out of the off-cuts from the lead used to connect to the inverter.

Start by making these four short connections. Expose a minimal amount of copper at the end of each wire (about 5mm) and be careful to avoid nicking the conductors when stripping the wires.

Earth connections

Now do the Earth wiring. Take one of the pieces of yellow/green striped wire you stripped out of the mains cable and cut it so that it will reach from the rear panel Earth bolt to the bottom panel Earth bolt. Strip both ends and crimp 4mm eyelets onto each.

You will also need an intact 40cm length of mains flex (which you may be able to make from the left-over length of mains cable). Strip back 5cm of outer insulation from each end and 5-10mm from each of the inner conductors. Crimp a 4mm eyelet onto the Earth wire at one end.

Then strip 5cm of the outer insulation from the end of the mains input cable and 5-10mm from the inner conductors and after feeding it through the cable gland on the rear panel, crimp a 4mm eyelet onto the Earth wire. Do exactly the same with the inverter output cable.

All four Earth eyelets can now be attached to the rear panel Earth bolt (M4 x 10mm) with a shakeproof washer between each and an M4 hex nut on top.

Do this up nice and tight. The other end of the wire with the second eyelet connector is then attached to the bottom of the case using a similar arrangement.

By the way, it would be perfectly valid to connect all the mains Earth wires together at the case bottom Earth bolt rather than the rear panel, as long as the rear panel is still Earthed to the base separately (since it can be detached when working on the unit). We simply used the rear panel because it kept the wiring neater.

Relay coil wiring

While not mains wiring, it's easiest to wire up the relay coil terminals before we complete the rest of the mains wiring. Use two short lengths of red light-duty hookup wire to join the three relay coil positive terminals, as shown in Fig.5.

Then cut four 1m-long lengths of light-duty hookup wire: red, orange, yellow and white. Connect them to the coil terminals at one end and the Arduino relay driver outputs as shown in the diagram.

Remaining mains wiring

The Active and Neutral wires of the length of mains flex can now be terminated to the two spare terminals on the back of the middle relay – see Fig.4 for details. Similarly, the Active and Neutral wires of the inverter output cable go to the terminals on the back of the relay closest to the corner of the case, and the plug on this cable can then go into one of the inverter outputs.

Before fitting the fuse holder into the case, solder a short length of brown wire to the terminal closest to the threading. Mount it in the rear panel and slip a long piece of 20mm diameter heatshrink tubing over the incoming mains cable. Next, solder the brown wire in that mains cable to the remaining fuse holder terminal (the one near the end).

Now move the heatshrink tubing up over the body of the fuse holder so that it covers both solder joints and shrink it in place.

We can then connect the Active and Neutral wiring for the third relay, closest to the transformer. There are three wires to go into each of these terminals: one from the incoming mains lead (or fuse holder, in the case of Active), one for the battery charger and one for the small mains transformer that's mounted next to the relay.

Cut the charger cable to 30cm, retaining the moulded figure-8 plug on one end. Strip the outer insulation back by 5cm and then strip around 5mm of the insulation from each of the inner conductors. The transformer wires should be supplied already stripped and the incoming mains lead should have been prepared earlier.

So now it's just a matter of feeding the sets of three wires into each terminal, careful to avoid any stray strands of copper sticking out, then do them up nice and tight.

The other end of the 40cm length of mains flex you cut earlier goes to the terminals on the four-outlet GPO. The Active, Neutral and Earth connections for the switchmode power supply units are attached to these same terminals.

Before making these connections though, cut a short (~5cm) length of brown wire, strip it at both ends and crimp a 6.3mm spade connector onto one end. This plugs into one of the rocker switch terminals, with the other end terminated to the Active input of the switchmode PSU.

Now cut 20cm lengths of blue, brown and yellow/green mains-rated wire and strip the ends, then attach these to the relevant switchmode PSU terminals, except for the brown wire. Crimp another 6.3mm spade connector to one end and plug this into the free terminal on the rocker switch.

You can now feed the other ends of these three wires into the GPO terminals, along with the wires from the central relay. Do this one terminal at a time, making sure you don't get them mixed up (follow the labels printed on the GPO terminals) and do them up firmly.

A quick test

Now it's time for a quick test. Insulate the transformer secondary wires and leave the relays out of their sockets, then stand clear of the unit and plug it into a wall socket. The battery charger should start up and you should be able to see the battery voltage rising using a DMM connected between the 0V and 24V terminals on the shield board. You should also be able to measure around 13-14VAC across the transformer secondaries.

The inverter can be tested by holding the power button next to its mains output socket for a second or so (without touching any of the other components). You can plug a lamp or other test load into the spare output socket to see that it's working properly. Shut the inverter down by pushing the power button again.

After ensuring the UPS not plugged into mains and the inverter is off, tidy up the mains wiring. Wherever two or more wires are terminated next to each other, cable tie them tightly together to provide a degree of security should one of them come loose.

Where the cables run next to each other, bundle them together. Your wiring should look like that in our photos.

Running the control wires

Now we can finish the control wiring shown in Fig.5. To connect the inverter to the Arduino, simply plug the telephone-style cable supplied with the inverter into the socket on the UPS shield and the other end into the inverter. Bundle the excess cable up with a cable tie and tuck it out of the way.

Use three 50cm lengths of light-duty hookup wire, two yellow and one white, to extend the secondary wires on the small mains transformer. Shrink short lengths of small diameter heatshrink tubing over the joins and terminate the wires into the three-way screw terminal on the control shield, with the white centre tap wire to the middle terminal.

Next, cut 70cm lengths of red and black medium-duty hookup wire and connect them to the DC outputs of the mains switchmode power supply mounted on the rear panel. Route these to the Arduino and connect them to the DC input terminals on the relay driver shield. Make sure the red wire goes to the +12V output and 5-24V DC input connections.

All the wires that run from the back to the front of the UPS are now in place, so take this opportunity to tidy them up using some self-adhesive cable clamps, P-clamps and a generous number of cable ties. If any of the cables are too long, bundle them up using cable ties so they won't move.

The remaining eight wires connect the 12V LED indicators and pushbutton on the front panel to the relay shield and UPS shield. The button wires are not polarised but the LED wires are. Connect these up as shown.

Solder the wires to the LEDs and button terminals and cover the joints with heatshrink tubing; clear is best as this allows you to see which wires go to the LED anodes and cathodes. The LEDs may have a small red dot on their positive (anode) terminal.

When finished, cable tie the bundle of eight wires together and strap it down.

The wiring is now complete, go back over your work and closely compare it to our diagrams and photos to make sure everything is as it should be. SC

In the third and final article on our UPS next month, we will test the completed UPS and explain how to interface it with a computer.

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Wind-up & Solar Cell Radio from Degen

by Ross Tester

You've seen those TV programs of "Preppers" – somewhat(!) eccentric people preparing for doomsday or such other catastrophic event by building nuclear blast-proof and radiation-proof shelters, stockpiling food, fuel and medicines, etc. Now Degen have come up with a small radio which will suit them down to the ground (or under it!). But the best part is that its features will suit everyone else – you don't have to be convinced the sky is falling in!

This rather neat little "CY-1" radio from Degen offers everything you'd expect – and then some – from a small, battery-operated portable radio – such as the AM band (522-1710kHz), FM band (87.0-108.0MHz) and even the shortwave band (3.0MHz-23.0MHz).

One interesting point: on the FM band, you can also select the wider "Campus Radio" band (64-108MHz) or the narrower Japanese FM band (79-90MHz). I'm not sure how useful these would be in Australia, though.

Also if you decide to take your radio overseas, you can select between 9kHz (standard Australian) and 10kHz (some overseas countries) AM channel spacing.

But it also has the ability to play MP3s (eg, on a TF card) and even has Bluetooth capability – and it can also record TO the TF card from radio or from its inbuilt microphone if you want to store, well, anything!

But wait, there's more!

The Degen CY-1 will operate from an internal rechargeable 3.7V/850mAh lithium ion battery (included) or from an external 5V supply (which, of course, will also charge the battery). And if you don't happen to have an external 5V supply (eg, after the bomb, or the alien invasion, or an asteroid wiping out all of civilisation except you . . . ?)

Here's what makes the Degen CY-1 so special: on the back of the radio is this wind-out hand crank which turns a dynamo inside, charging the battery. Or if that's not enough, there is the inbuilt solar cell on the top, which does the same thing.

Here's where it gets really interesting!

On the top of the radio is a solar cell which will power the radio and/or charge the battery (albeit rather slowly).

Uh-oh, no sunlight!

If you are in the middle of a "nuclear winter" or global darkness where the sun is well and truly hidden for weeks/months/years on end (well, it *could* happen, according to the experts) the Degen CY-1 has another trick up its sleeve, and what a trick: an inbuilt, hand-cranked dynamo! Simply unclip the crank from its hidey-hole on the rear panel and start winding . . . and presto, human power.

Mind you, you'll need to be pretty fit with plenty of time on your hands because with a dead-flat battery, I wound it fifty turns and was rewarded with about ten seconds of radio. But of course, if you're in your Prepper's cave after the "event" you will probably have *plenty* of time on your hands!

But I digress.

Other features of the Degen CY-1 include a 5V output (USB socket) which will give you several hours of power for your tablet/notebook computer or mobile phone (woops, mobile phone towers will already be knocked out by the "event" – ignore that remark), a micro-USB in/out socket, headphone socket (so you won't disturb the other cave dwellers) and (as we mentioned earlier) a micro-SD card socket (it can handle up to 32GB).

And just in case there are things going "thump" in the night, there's a bright white-LED torch PLUS a red flashing warning/distress LED (why you wouldn't use the white LED escapes me!). And finally, there's a rather loud distress "siren" (they call it an alert) to attract attention.

Seriously, though . . .

It's fine to poke fun at Preppers and the lengths they might go to but let's look at the Degen CY-1 as a radio in its own right, ie, for you and I in the "real" world.

First, the size: it's about 125 x 43 x 62mm – a handy size, not too large. The inbuilt speaker delivers about 600mW on maximum, more than enough for most applications. The lithium-ion battery will give you about five hours' play time – that's on both radio or MP3. It takes about the same time to charge from an external source (5V@~500mA – so computer USB ports will be fine as most can supply up to 1A).

Of course, if you operate the radio where sun can fall on its solar cell, you'll get much longer than five hours.

Degen maintain that cranking the inbuilt generator is more effective than using the solar cell to charge. That may be so but as I mentioned earlier, it didn't work that way for me. Then again, I hadn't noticed the clause in the instructions to turn the radio off before cranking – so they may well be correct.

To save the battery, the radio has an auto-power-off mode when you select "main menu" (which you get to by pressing the <ESC> key in any mode). The auto turn-off delay is only for three minutes.

If you're one who likes to doze off listening to the radio or music, that is a tad too quick. So you'd be much better off using the inbuilt Sleep Timer, which you can set for up to 90 minutes.

There is also an alarm built in with various modes, much like you'd expect to find on your mobile phone.

Incidentally, there are two rather intriguing entries (for a radio!) in the instruction manual. One is the "Text Browser (Ebook)" setting which simply says "text reading mode". If you have text files (.txt format) you can read the file on the radio's LCD screen.

The second is the notation of "Digital Radio" following FM/MW/SW on the unit itself, the box and the instructions. These days, you would be forgiven for assuming it also receives DAB+ Digital Radio. But no, it doesn't: I believe this simply means that it has a digital display.

There is no provision for an external antenna – the 34cm whip antenna is adequate (indeed essential) for FM reception and may assist somewhat with shortwave (there wasn't/isn't much on the shortwave bands when I was trying it out).

The whip doesn't do anything for AM reception which, if I must be truthful, I found at least a little lacking in sensitivity. In the city, there was no problem with local stations but even being able to select more distant stations exactly (by entering their frequency) was not overly successful.

I had the opportunity to try the same thing way out in the bush with not a great deal of luck. Scanning for stations which I knew existed only found some very strong ones but direct entry of station frequency was a little better.

I suspect the old bushie trick of connecting a long-wire

antenna to the whip with an alligator clip would do wonders for AM (and probably SW) reception (hang the impedance mismatch!).

FM reception with the whip extended brought in a large number of stations – then again, look at the FM stations register these days – there's millions of 'em! (OK, slight exaggeration). You can select FM mono or stereo if you wish (or want to listen to a weak FM station, where mono is the better choice).

Apart from the frequency ranges of each band, no other figures are given.

Music format

The "radio" will play music recorded on the micro-SD card in the three "big" formats – MP3, WMA and WAV. Yes, there are dozens (hundreds?) of other formats available but I believe Degen have made the right choice in limiting it to these three – they'll cover probably 95% of music tracks used today. With the limited size of the inbuilt speaker and similarly limited power output there would be no point in going for any of the more esoteric formats.

I tried recording a few MP3s to a micro-SD card just to verify its operation and it was exactly as the manual suggested. There is a variety of playback functions available, such as repeat, switch tracks, etc, much as you would expect to find on a typical MP3 player. Just as importantly, there is a "graphic equaliser" built in which allows you to set the genre of music from any of six types.

If your recording includes lyrics (in .lrc format) the CY-1 can display them for you – with a Chinese display if you're so inclined!

As I mentioned earlier, the CY-1 will also record to the card from either radio or from its inbuilt microphone.

Bluetooth

Two modes are available: you can play music files from your mobile phone (and presumably other Bluetooth devices) or you can answer and terminate incoming calls from your mobile phone.

There is no information on pairing or setting up Bluetooth in the manual and at time of writing, we hadn't the opportunity to play with Bluetooth.

Calendar/Time/Timer

These three functions are accessed by pressing the ESC key then the >> or << buttons. There is also a digital timer.

Conclusion

OK, that's the Degen CY-1 multi-powered AM/FM/SW radio. While we started out implying it was the perfect prepper present, on using it, we found it so much more. While there were a couple of points we found wanting, overall it had so much to offer (indeed, more than we've reported here) that it would also make a great general-purpose portable receiver.

And the fact that it can work from its inbuilt lithium-ion cell, or from its solar cell, or if you're feeling energetic its inbuilt dynamo (great if you forget to charge it!) really makes it a standout choice.

It's available direct from Tecsun Radios Australia (www.tecsunradios.com.au; phone [02] 9939 4377). Price is just $79.00 inc GST, plus postage – so with all its features, that makes it a very attractive package. SC

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A 4GHz digital attenuator module

This highly linear 4GHz digital attenuator is programmable over a range of 0-31.5dB in 0.5dB steps. This sort of attenuator is important in reducing signal levels in a circuit, to avoid overload in a mixer or amplifier. It could also be the basis of a precision full range attenuator in an RF signal generator.

This digitally programmed step attenuator module (available from Banggood, siliconchip.com.au/link/aaiy) has six internal cascaded attenuators which can be switched in or out independently, to provide an overall attenuation range of 0dB to -31.5dB in 0.5dB steps. The operating frequency range of the module is from about 1MHz up to 4GHz.

The module's PCB is just 33 x 24.5mm in size and RF input and the output SMA connectors are edge-mounted on each end of the PCB while there are power and programming inputs on the sides.

It uses a PE4302 IC in a 20-lead QFN (SMD) package measuring 4 x 4mm, from the San Diego-based (California) company Peregrine Semiconductor.

Their website (www.psemi.com) shows that they're part of the Murata group and that they make a wide range of RF ICs based on their patented "UltraCMOS" process.

This is an advanced form of silicon on insulator (SOI) technology. It now appears that the PE4302 is obsolete, having been replaced by the improved PE4312.

It is still available though, is significantly lower in price than the PE4312 and gives acceptable performance for non-critical applications. Banggood sell the module for just $11.00, but you can also purchase it on eBay or AliExpress.

Fig.1 is the block diagram of the PE4302. The six stages of the RF step attenuator are along the top, together with the DPDT analog switches which allow each stage to be switched in or out of the signal path between the RF_{IN} pin at upper left and the RF_{OUT} pin at upper right.

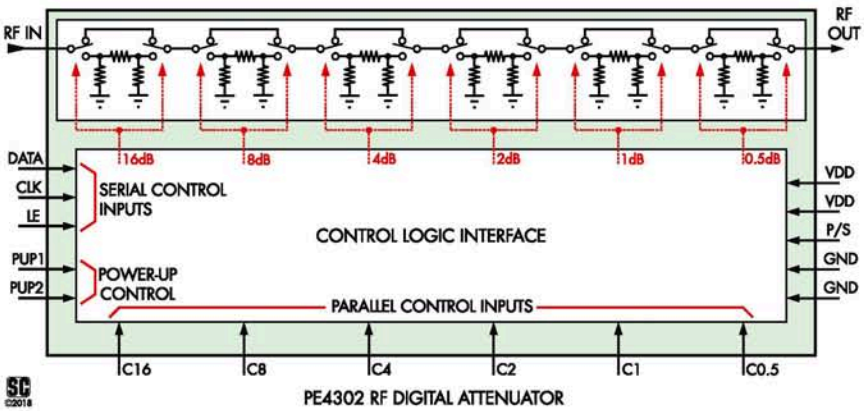


Fig.1: block diagram of the PE4302 attenuator IC. It has six attenuation stages which can be switched in or out by matching DPDT analog switches. Serial and parallel control inputs are both provided by the IC but the serial inputs are disabled on the PE4302 module.

The switches for each stage are driven by the Control Logic Interface shown in the lower part of the diagram. The first attenuation stage reduces the signal amplitude by 16dB while later stages reduce it by 8dB, 4dB, 2dB, 1dB and 0.5dB respectively.

Since these figures are all powers of 2, this allows the chip to be programmed in binary fashion to provide any desired nominal level of attenuation between 0dB and -31.5dB.

In practice, the chip has an insertion loss even at the 0dB setting (with all stages switched out).

Typically this insertion loss varies between -1dB and -1.5dB at frequencies below 2.5GHz, increasing to about -3.5dB at 4.0GHz. Oddly, this only seems to apply when there is no attenuation requested. As a result, the attenuation at a setting of -0.5dB is actually considerably lower than at 0dB for all the frequencies we tested!

The control logic interface provides parallel control inputs (along the bottom) and serial control inputs (centre left). That actually gives the PE4302 three different ways of setting the attenuation level.

Setting attenuation

The first way of setting attenuation level is via direct parallel programming, where you apply logic-level

signals directly to the C16-C0.5 inputs with a microcontroller or a set of DIP switches.

The second mode is latched parallel programming, where the control signals are still applied to the C16-C0.5 input pins but the LE (load enable) pin must be pulsed low when they are changed because the control signals are stored in a latch register when the LE pin is returned to logic high.

The third mode is serial programming, where the six programming bits are fed into the chip via the CMOS-compatible DATA and CLK serial interface pins, with the LE pin then pulsed high and low to store the bits in the latch. If the P/S pin is pulled high, the chip powers up in serial programming mode; otherwise, it powers up in parallel mode.

When parallel mode is enabled, the PUP1 and PUP2 pins at lower left in Fig.1, together with the LE pin at centre left, are used to determine the chip's control settings when it is powered up.

By varying the logic levels on these pins you can ensure that the chip powers up at 0dB attenuation (insertion loss only), 8dB, 16dB or 31dB, or whatever attenuation is programmed by pins C16-C0.5.

Fig.2 shows the complete circuit of the step attenuator module and it is set in direct parallel programming mode. This has the LE pin (5) tied to the positive supply rail while the P/S, PUP1 and PUP2 pins (13, 7 & 8) are all tied to ground, along with the DATA (3) and CLK (4) serial interface pins.

The RF input connector is coupled to pin 2 of IC1 via a 100nF capacitor, while the output is taken from pin 14 to the RF output connector via another 100nF capacitor.

The parallel programming pins C8 (15), C4 (16), C2 (17), C1 (19) and C0.5 (20) are each connected to pins V5-V1 on the 7-way SIL programming connector CON1 as well as being pulled to ground (logic low level) via 10kΩ resistors. The C16 (1) programming pin is connected in a similar fashion to pin V6 of CON1, although not directly but via a series 10kΩ resistor.

This is in line with Peregrine's recommendation, to prevent resonance effects within the chip due to the proximity of this pin to the RF_{IN} pin (2).

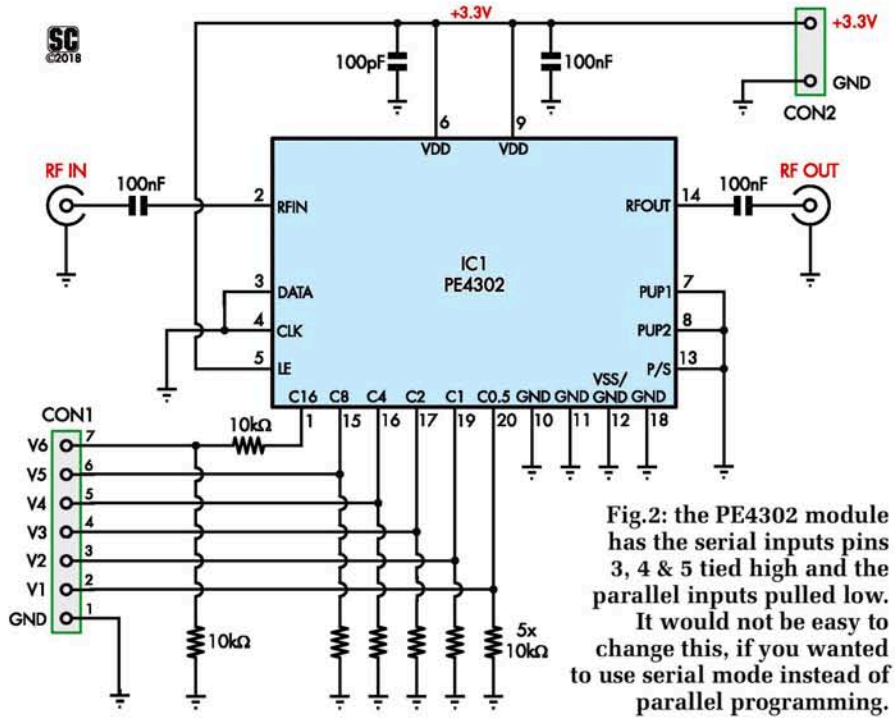


Fig.2: the PE4302 module has the serial inputs pins 3, 4 & 5 tied high and the parallel inputs pulled low. It would not be easy to change this, if you wanted to use serial mode instead of parallel programming.

Putting it to use

The simplest way to control this module is to use a 6-pole DIP switch, as shown in Fig.3. One side of each switch is connected to the +3.3V supply line so that when each switch is closed, the respective pin of CON1 will be pulled high.

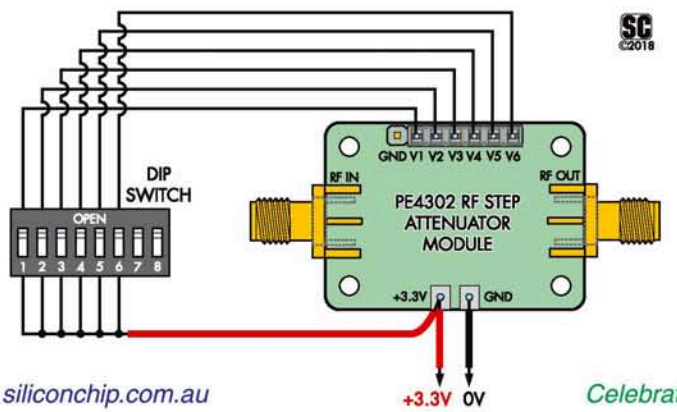
The truth table to the right of Fig.3 shows some examples of the switch combinations and the resulting nominal attenuation settings.

You could use a similar approach to control the module directly from a micro, like an Arduino or a Micromite. In this case, you'd power the module from the +3.3V and GND pins of the micro and connect programming pins V1-V6 to six spare digital I/O pins on the micro.

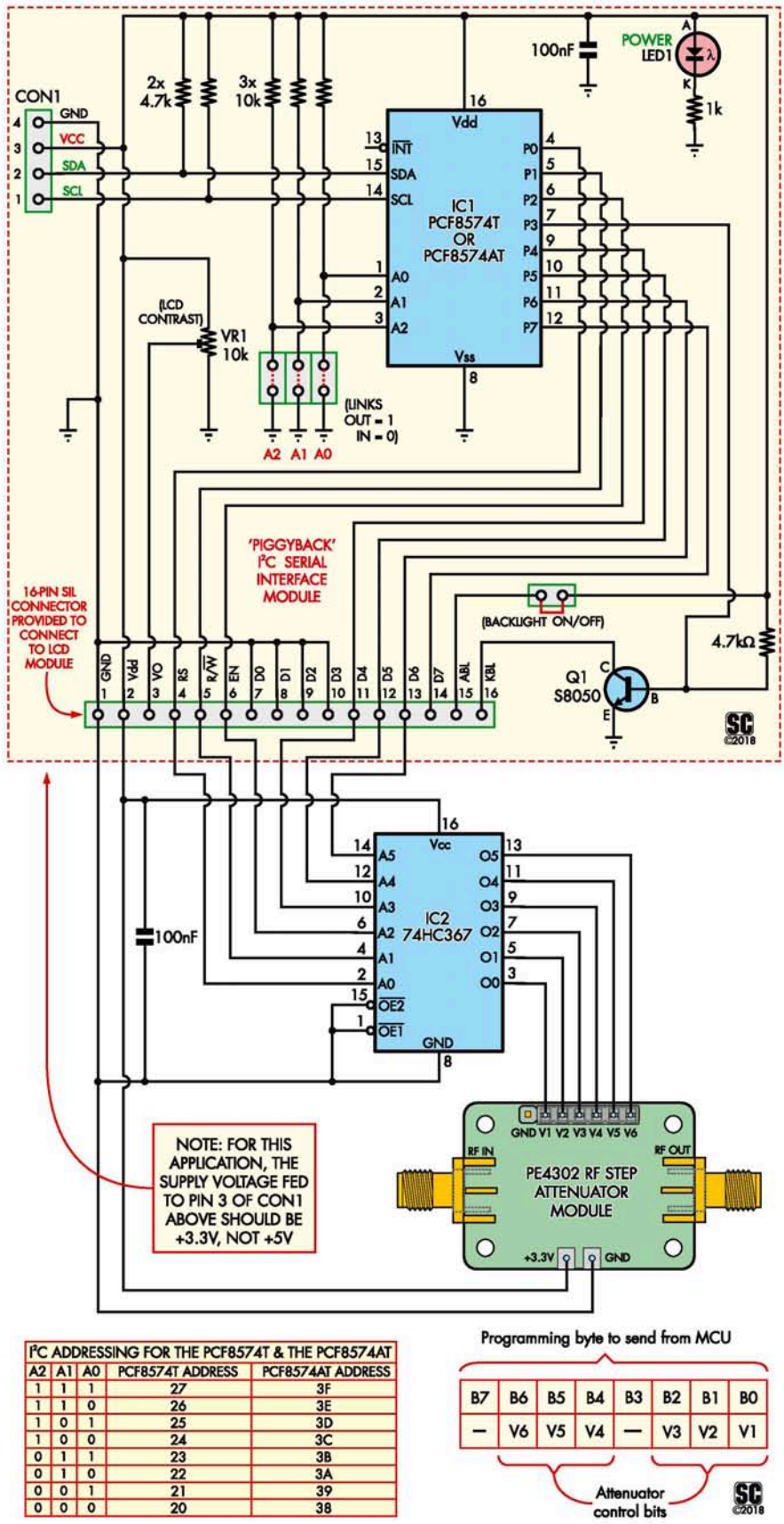
Then it would be a matter of writing a program to control the attenuator module via these six pins.

The difficulty with this approach is that you may not have six spare I/O pins available. Unfortunately, as noted, the module is hard-wired for parallel programming, with the serial interface effectively disabled.

Fig.3: manual programming can be done with a 6-pole DIP switch attached to the PE4302 module. The table below shows some of the switch combinations and the resultant attenuation settings.



PE4302 Programming Truth Table						
V1 (C0.5)	V2 (C1)	V3 (C2)	V4 (C4)	V5 (C8)	V6 (C16)	ATTENUATION
0	0	0	0	0	0	(Insertion loss only)
1	0	0	0	0	0	0.5dB
0	1	0	0	0	0	1.0dB
0	0	1	0	0	0	2.0dB
0	0	0	1	0	0	4.0dB
0	0	0	0	1	0	8.0dB
0	0	0	0	0	1	16dB
0	1	0	1	0	1	21dB
1	1	1	1	1	1	31.5dB



I²C ADDRESSING FOR THE PCF8574T & THE PCF8574AT				
A2	A1	A0	PCF8574T ADDRESS	PCF8574AT ADDRESS
1	1	1	27	3F
1	1	0	26	3E
1	0	1	25	3D
1	0	0	24	3C
0	1	1	23	3B
0	1	0	22	3A
0	0	1	21	39
0	0	0	20	38

Programming byte to send from MCU

B7	B6	B5	B4	B3	B2	B1	B0
—	V6	V5	V4	—	V3	V2	V1

Attenuator control bits

Fig.4: wiring diagram for the PE4302 module connected to a serial I²C "piggyback" module (IC1) via a hex non-inverting buffer (IC2). At bottom right is the format of the byte to be sent from the micro to the PE4302 to activate each attenuator. Ergo, 01110110 (big-endian) activates C1, 2, 4, 8 & 16 (but not C0.5).

Luckily, there is a way to work around this so you can control the module from your micro via a standard I²C serial interface. That's by making use of one of the very low cost piggyback serial interface modules, based on either the PCF8574T chip or its sibling, the PCF8574AT.

These modules are intended to adapt a parallel-interface LCD module for serial interfacing and they often come mated with an LCD.

But they are also available separately for less than $2 each and this makes them very attractive for solving other I²C/parallel interfacing jobs like this one.

Fig.4 shows how to use one of these PCF8574T/AT modules to connect up the PE4302 digital step attenuator module to your micro for serial control via the I²C bus.

The upper part of the diagram shows the circuitry inside the piggyback module, while the PE4302 module is shown at lower right, with the interconnections all made via the 16-pin header which usually connects to the LCD module.

The six programming lines pass through IC2, a 74HC367 hex non-inverting buffer. This is needed because the outputs from IC1 can only provide very low current in their high logic state but the V1-V6 inputs of the step attenuator module are all fitted with 10kΩ pulldown resistors.

This means that they tend to draw more current than the outputs of IC1 can provide.

Alternatively, you could leave out the 74HC367 and simply remove the six pull-down resistors from the underside of the module.

Notice that we've also shown a table at lower left in Fig.4 with the various I²C addresses applying to the piggyback module, depending on (a) whether it's using a PCF8574T chip or a PCF8574AT chip, and (b) whether any of the onboard links A0, A1 or A2 are shorted.

If you're in any doubt regarding which of the two chips is fitted to your module, this can usually be clarified quite easily by examining the top of the chip with a magnifying glass.

Note that because the PE4302 chip must be connected to a 3.3V supply, this also means that pin 3 of CON1 on the piggyback module should be connected to +3.3V rather than the usually expected +5V.

This won't be a problem for the piggyback module because both versions of the PCF8574T/AT are designed to work from any supply voltage between 2.5V and 6V.

As shown in Fig.4, you connect pins V1-V3 of the attenuator module to pins 4-6 on the piggyback module (via IC2), while pins V4-V6 are connected to pins 11-13.

As a result, to program the attenuator correctly you simply need to send it the six control bits embedded in a single byte as shown at bottom right.

Note that bits B3 and B7 are not used and can be left at either zero or one.

Performance testing

I measured the performance of the digital step attenuator with my VHF/UHF signal generator and power meter. Because of the larger number of possible attenuation factors, this inevitably took rather long, even though I elected to do measurements for only 12 of the 64 combinations of programming bits.

But I did take measurements at eight different frequencies, at 100MHz, 1.0GHz, 1.5GHz, 2.0GHz, 2.5GHz, 3.0GHz, 3.5GHz and 4.0GHz.

Note that the measurements were taken at nominal attenuation factors of 0dB (ie, insertion loss only), -0.5dB, -1.0dB, -2.0dB, -4.0dB, -8.0dB, -16.0dB, -20.0dB, -24.0dB, -28.0dB, -30.0dB and -31.5dB.

These were chosen to give a good idea of the module's overall performance.

The results are quite close to the nominal values shown in the left-hand column of Table 1. For example, the measured value for a nominal attenuation factor of -16.0dB at 1.5GHz turns out to be -16.06dB; pretty darn close.

Similarly, the measurement at 3.5GHz for a nominal attenuation of -8dB proved to be -7.95dB. Again, not far off.

Overall, the performance is quite good, at least for frequencies up to about 1.5GHz but at higher frequencies, the relative accuracy does seem to deteriorate somewhat.

I suspect that there are two reasons for this, one being that the open construction of the module probably allows some of the RF input signal to "jump over" the PE4302 chip package, especially at frequencies of 2.0GHz and above (ie, due to stray capacitance).

The other likely reason is that the input and output impedances of the PE4302 almost certainly vary from 50Ω at these higher frequencies, causing standing waves in the cables.

In fact, the Peregrine Semiconductor data sheet shows both the input and output return loss plots varying quite widely over the full frequency range. Both rise significantly at higher frequencies.

There's probably not much that can be done about the cable matching/standing waves problem since it's inherent in the chip itself.

Not content with that, I decided to try improving the overall attenuation accuracy at the higher frequencies by fitting an earthed metal shield over the PE4302 chip and its input and output coupling capacitors.

The shield measured 33 x 7 x 2.5mm and was soldered at each end to the earthed outer frame of the SMA connectors.

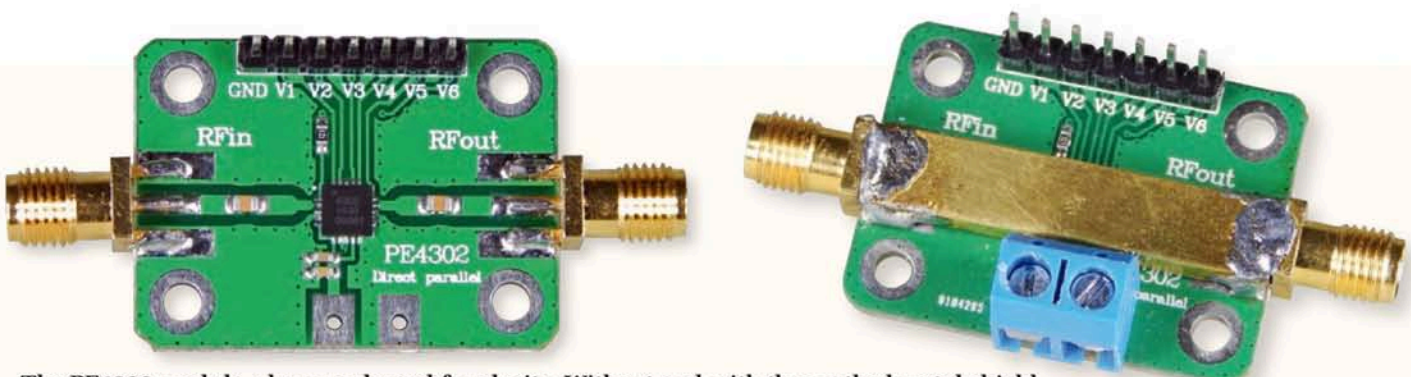
Table 2 shows the modest improvements after the shield was fitted so it is probably a worthwhile exercise for very little effort. SC

TABLE 1: MEASURED PERFORMANCE OF PE4302–BASED DIGITAL STEP ATTENUATOR

NOMINAL ATTENUATION	MEASURED RELATIVE ATTENUATION IN DECIBELS (excluding cable losses)							
	@100MHz	@1.0GHz	@1.5GHz	@2.0GHz	@2.5GHz	@3.0GHz	@3.5GHz	@4.0GHz
0dB	–1.22	–1.51	–1.80	–1.80	–1.37	–2.76	–5.30	–5.22
–0.5dB	–0.53	–0.50	–0.38	–0.60	–0.75	–0.78	–0.76	–0.71
–1.0dB	–1.01	–0.98	–0.90	–1.18	–1.36	–1.30	–1.11	–1.08
–2.0dB	–2.08	–2.09	–2.00	–2.32	–2.76	–1.37	–2.19	–1.97
–4.0dB	–4.12	–4.12	–4.05	–4.42	–5.02	–4.76	–3.98	–3.72
–8.0dB	–8.08	–8.04	–7.99	–8.29	–9.15	–8.81	–7.95	–6.92
–16.0dB	–16.08	–16.08	–16.06	–17.11	–17.54	–17.31	–16.19	–12.20
–20.0dB	–20.09	–20.06	–19.87	–19.57	–21.26	–21.04	–18.88	–14.16
–24.0dB	–24.01	–23.74	–23.14	–22.60	–24.20	–23.52	–20.05	–24.53
–28.0dB	–28.03	–27.37	–26.20	–25.31	–26.77	–25.49	–20.68	–15.47
–30.0dB	–30.02	–29.12	–27.24	–26.44	–27.81	–26.38	–20.99	–16.26
–31.5dB	–31.51	–30.22	–28.02	–27.57	–28.40	–26.75	–21.28	–16.67

TABLE 2: MEASURED PERFORMANCE OF PE4302–BASED DIGITAL STEP ATTENUATOR (with shield)

NOMINAL ATTENUATION	MEASURED RELATIVE ATTENUATION IN DECIBELS (excluding cable losses)							
	@100MHz	@1.0GHz	@1.5GHz	@2.0GHz	@2.5GHz	@3.0GHz	@3.5GHz	@4.0GHz
0dB	–1.25	–1.57	–1.62	–1.73	–1.30	–2.31	–4.35	–6.45
–4.0dB	–4.11	–4.13	–4.23	–4.53	–4.95	–4.88	–4.16	–4.22
–8.0dB	–8.04	–8.01	–8.18	–8.54	–9.15	–9.05	–8.21	–8.72
–16.0dB	–16.06	–16.72	–16.38	–16.64	–17.71	–17.95	–18.03	–18.98



The PE4302 module, shown enlarged for clarity. Without and with the earthed metal shield.

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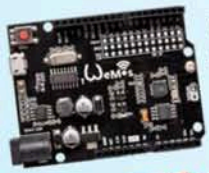

WeMos D1 R2 WiFi Board
A WeMos D1 R2 Arduino-compatible WiFi board which includes a connector for an external antenna. This is a clone board used in the WiFi Water Tank Level Meter (Feb 2018) SC4414 – **$15.00**

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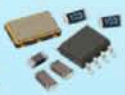
5m Water Level Sensor (4-20mA)
Pressure-based water level sensor with a 5-6m lead as used in the WiFi Water Tank Level Meter (Feb 2018)
SC4283 —— **$95.00**

Microbridge complete kit
Includes PCB, programmed micro & IC socket, 3.3V LDO, all capacitors, USB socket, pin headers and 1kΩ resistor (May 2017) SC4264 —— **$20.00 ea**

AD9833 DDS module
A Direct Digital Synthesis module using the AD9833 IC and a 25MHz crystal oscillator. (April 2017)
with programmable attenuator SC4205 —— **$25.00**
without attenuator SC4204 —— **$15.00**

Elecrow 1A/500mA Li-Ion/LiPo charger board with USB power-pass through
Provides a regulated 5V output at 500mA from the cell, plus a 1A charger and automatic input-to-output pass-through. Supplied with three 2-wire JST 2.0 cables SC4308 — **$15.00 ea**

Isolated High-Voltage Probe
Pack of hard-to-get parts including HCNR201-050E linear optocoupler, op amps and HV capacitors & resistors (Jan 2015) SC2919 —— **$35.00**



SiDRADIO parts
125MHz crystal oscillator, mixer, dual gate Mosfet, 5V relay and more SC2137 – **$20.00**
RF Coil Former pack SC2746 —— **$5.00**

Parts for the AV modulator for Vintage TVs
RF Coil Former pack SC2746 – **$5.00**
MC1374P AV modulator IC SC4543 —— **$5.00**

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2dBi omnidirectional (28mm) SC4523 – **$10.00**
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Logic-level Mosfets
2 x CSD18534KCS N-channel SC4177 – **$5.00** **or** complementary pair of N & P-channel Mosfets (as used in Burp Charger) SC2640 – **$7.50**

IPP80P03P4L04 P-channel Mosfet
A high-current P-channel Mosfet with low on-resistance in a TO-220 package. Used in the Water Tank Level Meter (Feb 2018) and AM Radio Transmitter (Mar 2018) SC4318 – **$4.00**

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Includes PCB, LDR, high-brightness blue LED, all SMD parts, an extra capacitor plus extra resistors to change flash frequency and duty cycle (Feb 2017) SC4125 – **$12.50**

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Temperature and humidity module as used in the Water Tank Level Meter and other projects (February 2018) SC4150 —— **$7.50 ea**

ESP-01 WiFi module
A small WiFi module with an ESP8266 IC and onboard antenna. Used in the GPS Time Source project (April 2018) SC3982 – **$5.00**

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3.3V LDO regulator in a convenient TO-92 package; up to 6V input and 250mA output SC2782 — **$1.50**

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CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Atari Punk Console 4-16 step synthesiser/sequencer

The "Atari Punk Console" is a simple sound synthesiser based on a 556 dual timer. This version allows you to program in a short tune (or sequence), consisting of between four and 16 notes, depending on how many potentiometers you use.

Each trimpot sets the tone of one of the notes in a sequence and the notes are played in round-robin fashion with an equal time for each.

The concept was originally published in 1980 and popularised around 1984 (see Wikipedia at: https://en.wikipedia.org/wiki/Atari_Punk_Console) for more details. It was not actually used by Atari but is named as such because the sound it produces is similar to that of early gaming consoles.

Essentially, it's a basic analog sequencer and all you need to drive it is a 5-12V DC power source (eg, a USB port) and a pair of headphones or earphones (or possibly a small speaker).

There are two main sections to the circuit, the sequencer and the sound synthesiser. The sequencer consists of IC1, a 4017B decade counter/divider, and IC2, a 555 timer. IC2 is configured as an astable oscillator which provides pulses to the CLK input of IC1.

Potentiometer VR1 adjusts the frequency of these pulses and therefore the rate at which the sequencer steps through the notes while LED1 flashes briefly each time the unit progresses to the next beat.

The first four outputs of the decade counter (O0-O3) feed 470kΩ potentiometers via diodes and these pots control the tone of each note.

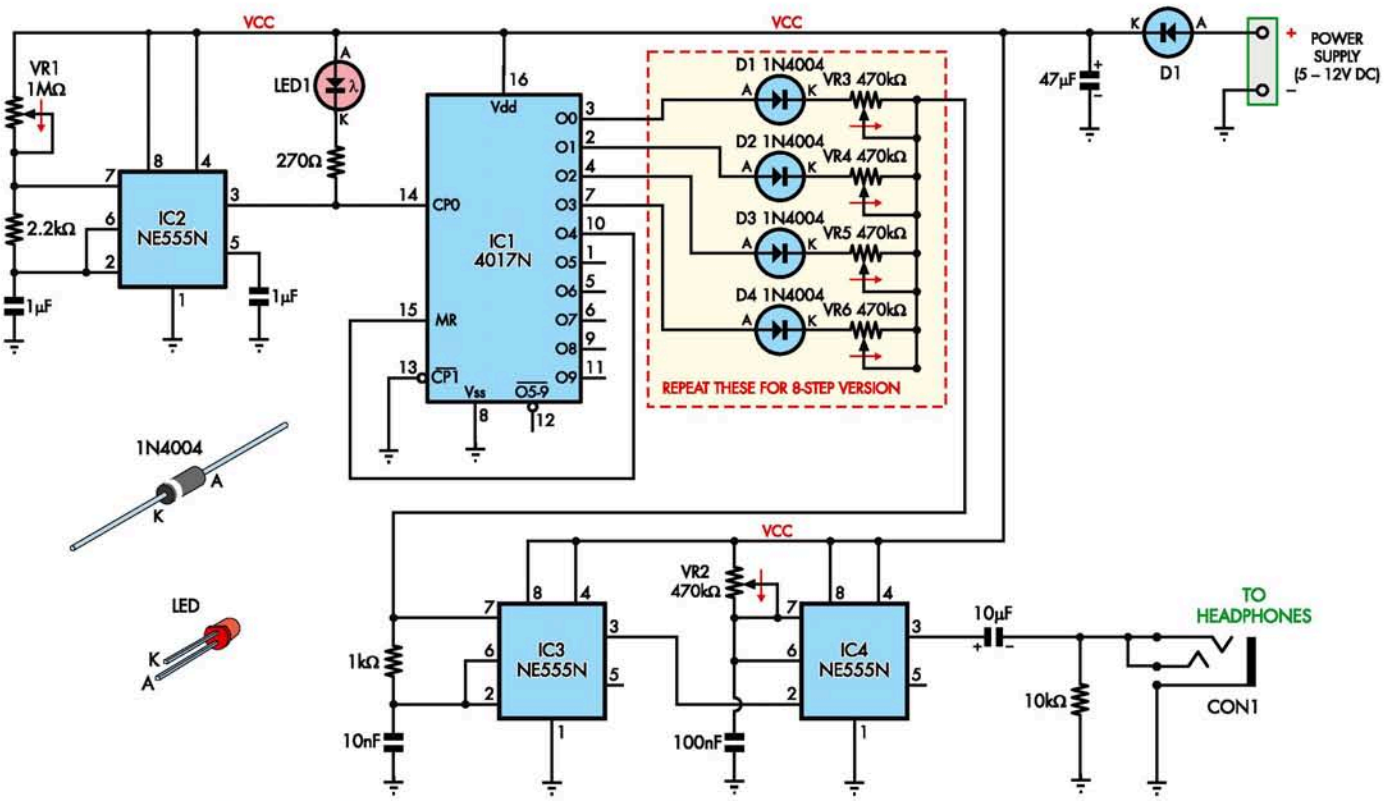
The fifth output (O4, pin 10) is wired directly to the master reset input (pin 15) so that, after playing the four notes, it starts again with the first one and the sequence repeats indefinitely.

While the circuit is shown with only four pots and thus gives you four beats, you could easily extend it to eight beats by moving the reset connection to output O8 (pin 9) and then connecting another four diodes and pots to outputs Q4-Q7, in the same manner as for Q0-Q3. We'll explain how to extend it further but not just yet.

The current from whichever potentiometer is selected by the sequencer is fed to pin 7 of IC3, the discharge pin, and charges the 10nF capacitor via the additional 1kΩ series resistor.

IC3 is also configured as an astable oscillator and since the current from that potentiometer controls how fast the capacitor charges, it also controls the oscillation frequency. Note that this frequency has a step change each time the sequencer selects the next pot.

IC3's output pin 3 drives the trigger



SC ©2018 4-TO-16 STEP SYNTHESISER/SEQUENCER

input (pin 2) of IC4, another 555. This is set up as a monostable pulse generator with a pulse duration set by VR2. So IC3 and IC4 interact to produce a square wave with a particular frequency and (potentially changing) duty cycle which results in a distinctive tone. The pulses are fed through a capacitor to the headphone jack.

IC3 and IC4 could be two halves of a single 556 dual timer if desired and indeed, the original APC or "Stepped Tone Generator" was designed that way.

Expanded version

The circuit below shows how to extend the unit to more than eight beats. It involves cascading the 4017B counters; they aren't designed to be combined in this way but it can be done.

Both timers are reset simultaneously at power-up by a 10nF capacitor from V_{CC} to the anode of diodes D21 and D22. This charges in around 10µs and releases the reset for both ICs. Diode D23 ensures this capacitor discharges quickly at switch-off.

With both ICs reset, their O0 output pins are high and this pulls the CP0 input (pin 14) of IC5 high. Note that we're using the CP0 input as an active-high enable input and the $\overline{CP1}$ pin as the actual (inverted) clock; this is permissible since both inputs feed into a single logic gate which ultimately clocks the internal flip-flops.

So on the next pulse from IC2's output pin 3, both counters will advance and their O1 outputs will be high. IC1's O1 output is connected to the reset pin of IC5 via a 1kΩ resistor, so IC5 will immediately be reset.

Because the pots are now connected to output pins O1-O8 of each counter, that means VR3 will be the first active pot. And since output O1 of IC1 is now high, the clock enable signal to pin 14 of IC5 will now go low (it's only high when O0 or O8 of the IC1 is high). So IC5 will remain in its reset state while IC1 steps through outputs O1-O8 as in the original circuit.

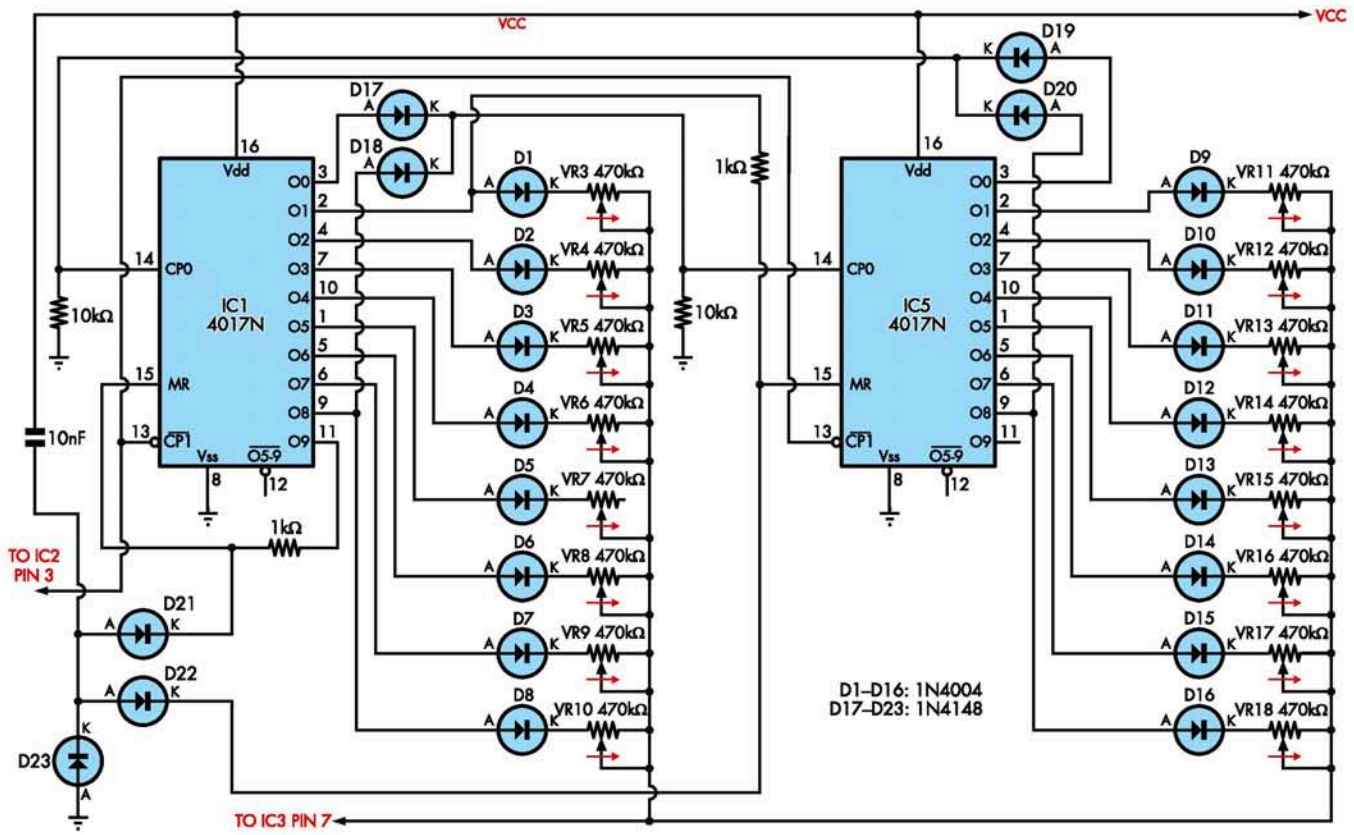
When IC1's Q8 output goes high and the eighth beat begins, D18 is forward-biased and IC5's clock is re-enabled. So on the next pulse from IC2, IC1 enables output O9 while IC5 enables output O1.

IC5 then steps through the next eight beats as it enables outputs O1-O8 in turn, while IC1 resets itself and since its clock is disabled, it remains with output O0 enabled.

IC1's clock is re-enabled once IC5's output O8 goes high, and so on the next clock pulse, IC1's output O1 goes high, resetting IC5. And thus the cycle of sixteen beats repeats.

This same principle could be extended to more than two 4017B ICs, for even more beats, although the circuit would become unwieldy.

Dre West,
Paddington, Qld. ($80)



MODS FOR 16-STEP VERSION OF APC SYNTHESISER

Circuit Ideas Wanted

Got an interesting original circuit that you have cleverly devised? We will pay good money to feature it in Circuit Notebook. We can pay you by electronic funds transfer, cheque or direct to your PayPal account. Or you can use the funds to purchase anything from the SILICON CHIP on-line shop, including PCBs and components, back issues, subscriptions or whatever. Email your circuit and descriptive text to editor@siliconchip.com.au

Use your phone to capture glitches on a scope

I'm currently designing a PC-controlled battery analyser and needed to check the rise time of a one-off event that only happened after a few minutes.

It would have been really handy if I had a DSO (Digital Storage Oscilloscope). I could have set it up for the right trigger conditions, waited for it to trigger and than examined the result.

I do have a Tektronix 350MHz scope, but it doesn't have storage. I tried closely watching the scope display several times but it's very hard to see a 100ms long event that only happens after a few minutes.

I considered buying one of the El-Cheapo $30 DSOs on eBay but decided against as they take 4-6 weeks to arrive and they have quite a few bad reviews online.

Eventually, I had an epiphany – I could use my iPhone to make a video of my scope's screen and then play it back to see if I had captured this one-shot event. This works extremely well and the rise time that I needed to measure was easily seen on my iPhone, although the screen was smaller than I would like.

To get a really clear view, I uploaded the video to my PC, opened it with a video player, fast forwarded it until I found the event and then slowed the playback speed until I found exactly what I was after. You can see the result in the image below. As shown, the total rise time is around 140ms.

This won't give you all the features of a DSO and you do need access to a scope but it's a good solution deal for zero dollars.

Geoff Cohen,
Nelson Bay, NSW. ($50)

Low-cost Automotive Ammeter

There are many LED digital ammeters available nowadays and they seem very suitable for use in motor vehicles.

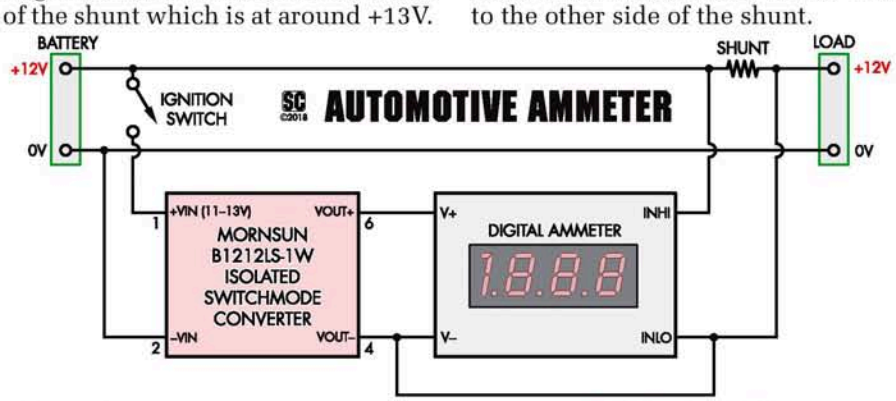
However, there is a major difficulty in that most of them require a ground-referenced sense voltage, generated by a low-value shunt between the battery ground and load ground connections.

Because the battery and alternator in most vehicles are connected directly to the vehicle chassis (in the case of the alternator, via its the mounting bolts), you can't easily insert a shunt in the ground-connected part of the circuit.

So you have to use high-side sensing, and if you want to incorporate one of these LED ammeters, you need an isolated 12V supply for the module so its ground can be connected to one side of the shunt which is at around +13V.

This means you need a DC/DC converter which will handle a 12V input and produce a 12V output with isolation between the input and output. One such device is the Mornsun "Godsend" B1212LS, which is available from eBay and other sources. This has an input range of 10-16V and can deliver up to 1W (ie, just under 100mA).

As shown in the circuit diagram, wire the converter's inputs to the vehicle's switched 12V supply rail (pin 1) and chassis ground (pin 2), then connect its negative output (pin 4) to the end of the shunt which will have a lower voltage (towards the load). The ammeter is then connected to the module's outputs as normal (pins 4 [-] and 6 [+]), with the third "sense" wire to the other side of the shunt.



Note that many LED ammeters do not have an INLO connection as this is internally connected to V-. This common negative terminal may be labelled "COM", with INHI possibly labelled as "IN+" and V+ may be "PW+".

The ammeter modules normally expect 75mV between sense and ground for a full-scale display, so use a 75mV shunt rated for the same maximum current as the meter. They are typically available for currents from 10A to 500A, also on eBay (see links below).

Note that you can also get combined ammeter/voltmeter units but because we aren't running the ammeter from the vehicle's 12V supply, it is preferable to use a separate voltmeter instead.

In the case of the Mornsun module, when lightly loaded, its output voltage tracks the input voltage quite well so you might be able to get away with it. Other converters may regulate their outputs, however, rendering an integrated voltmeter useless.

LED ammeters: www.ebay.com.au/itm//201926527771

75mV 10-100A shunts: www.ebay.com.au/itm//262852275183

Mornsun B1212LS-1WR2: www.ebay.com/itm//301938928240

John Russull,
Cambodia. ($50)

PICAXE-based Millisecond Reaction Timer

Check your reaction time and also the reaction times of your family and friends with this simple device. It checks how long it takes you to recognise an LED switching on and translate that into the motion of your hand to press a button.

You can expect reaction times between 100ms and 250ms when you operate the pushbuttons by hand or times up to 350ms if you connect a foot pedal.

Reaction times are important for a number of activities such as driving a car, playing sports, in an emergency situation and so on. For example, it reflects the time between a person running out onto the road and you pressing the brake pedal on a car or truck.

The way this timer works is that you press the start button and the WAIT LED lights. Then there is a random delay of between two and six seconds, after which the RUN LED lights.

You then press the STOP button as quickly as you can. The time between the RUN LED lighting and you pressing the STOP button is displayed in milliseconds on a 3-digit, 7-segment LED display.

The program uses a software counter running on the PICAXE20M2 microprocessor (IC1) to determine your reaction time. Its internal timer is quite accurate over the span of one second.

The micro also multiplexes the 7-segment displays by driving the three sets of eight paralleled display anode pins (a-g) via 100Ω current-limiting resistors and the segment common cathode pins using BC337 transistors Q1-Q3 with 1kΩ base current-limiting resistors.

The user control panel has two LEDs and three tactile or snap-action pushbuttons and connects to pins 3-7 on microcontroller IC1. The input pins connected to pushbuttons have high-value pull-up resistors enabled inside IC1.

The unit powers up in standby mode when switched on using S1 or after the clear button (S3) is pressed. This mode blanks all three 7-segment displays (DISP1-3) and illuminates LED1.

To test your reaction time, press START button S2 and wait until LED2 turns on. You then have one second (999ms) to press STOP button S4, determining your reaction time.

Pressing the STOP button (S4) early will prevent the run indicator (LED2) from turning on. Assuming you performed the sequence correctly, your reaction time will be shown on the 7-segment display.

After you view your reaction time, press the CLEAR button (S3) to return to standby mode. Piezo transducer PS1 beeps each time a button is pressed.

Power is from a 6V battery (4 x AA or similar) with diode D1 to reduce the voltage to IC1 to around 5V, while also providing reverse battery protection.

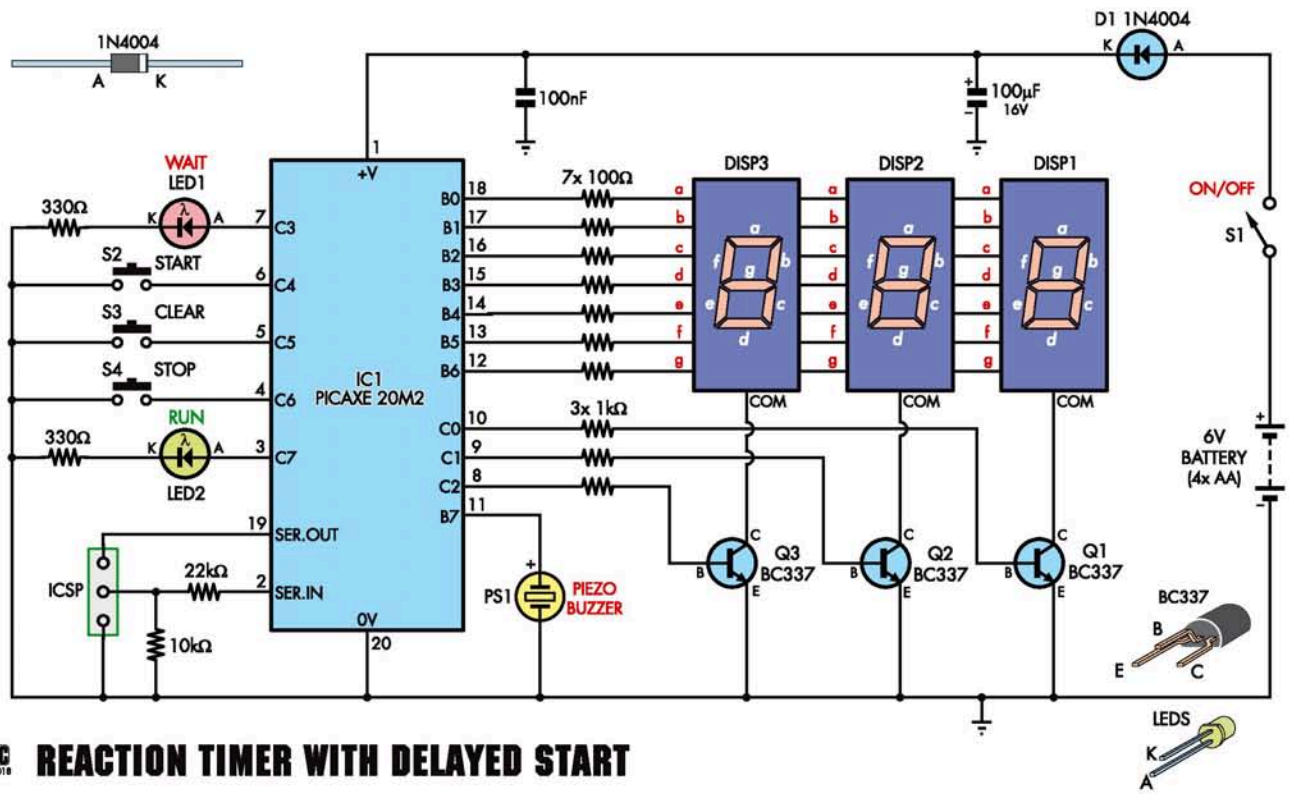
I recommend the red Altronics Z0190 or blue Jaycar ZD-1856 for the three 7-segment displays. Piezo buzzer PS1 can be the Altronics S6140 or Jaycar AB-33440.

The prototype reaction timer was built in medium size Jiffy box with the components soldered to IC-pattern strip boards (designed for prototyping circuits with DIP ICs).

I used sockets to mount the 7-segment displays, raising them above the board and make them level with the pushbuttons and the LED indicators.

The finished unit should be placed on the table with the user controls and the 7-segment display facing upwards, as this prevents the Jiffy box moving as the buttons are pressed.

The circuit includes a serial programming header (ICSP) to load programs into PICAXE microcontroller IC1, with pin 2 of IC1 for serial and pin 19 for serial output. You need a PICAXE programming cable and the free "program editor software" from



SC ©2018 **REACTION TIMER WITH DELAYED START**

the PICAXE website.

You can download the PICAXE BASIC program, named "reaction_timer_20m2.bas", from the SILICON CHIP website and load it into the chip using the aforementioned software.

Ian Robertson,
Engadine, NSW. ($60)

Servomotor tester

This Remote-controlled Servo Tester has been designed to check a servomotor's operation easily. Servos normally use a pulse control signal, with pulses at 50Hz.

A pulse of nominally 1.5ms centres the motor, while shorter pulses (down to 1ms) move it off-centre in one direction and longer pulses (up to 2ms) move it in the other direction.

This circuit generates pulses from 0.5ms to 2.5ms at the standard 50Hz rate, with the pulse width varied using potentiometer VR1. The current pulse width is displayed on an alphanumeric LCD.

The range is larger than the standard 1-2ms range and care should be exercised as damage can be done to a servo due to excessive motor currents.

Consequently, the servo supply should be current limited such as using four AA alkaline cells for testing or an RC filter with the resistor limiting the continuous current that the motor can draw from the 6V supply.

Note that most servos use the pinout shown here, with the red positive supply wire being in the middle, the negative supply wire normally black or brown and the signal wire usually orange, yellow or white.

However, some servos use a different configuration so you will have to check before wiring it up.

The circuit is very simple with the PIC16F616 doing all of the testing. It operates at 5V which is supplied by the low-dropout MCP1702 regulator and which is itself supplied from the 6V source via 1N5819 schottky diode D1.

Its input is bypassed with 10µF and 1000µF capacitors which act to isolate the regulator from momentary supply drops due to servomotor current surges.

The adjustment potentiometer has a 100nF capacitor between its wiper and ground to ensure a low source impedance for the PIC's analog-to-digital (A/D) converter.

It's designed for an alphanumeric LCD with a Hitachi HD44780-compatible controller and English character set. This is denoted by the A00 suffix but most LCDs have the controller hidden under black resin so you will need to check the manufacturer's data sheet. The LCD is driven in nibble (4-bit) mode, with data lines D0 to D3 tied to ground.

The program reads the potentiometer position in a loop and if the value differs more than the equivalent of 10µs from the current pulse width, the output pulse will be adjusted accordingly.

So the pulse width adjustment resolution is 10µs. Lower than this, it is difficult to adjust the pulse width to a set value and the reading is likely to jitter.

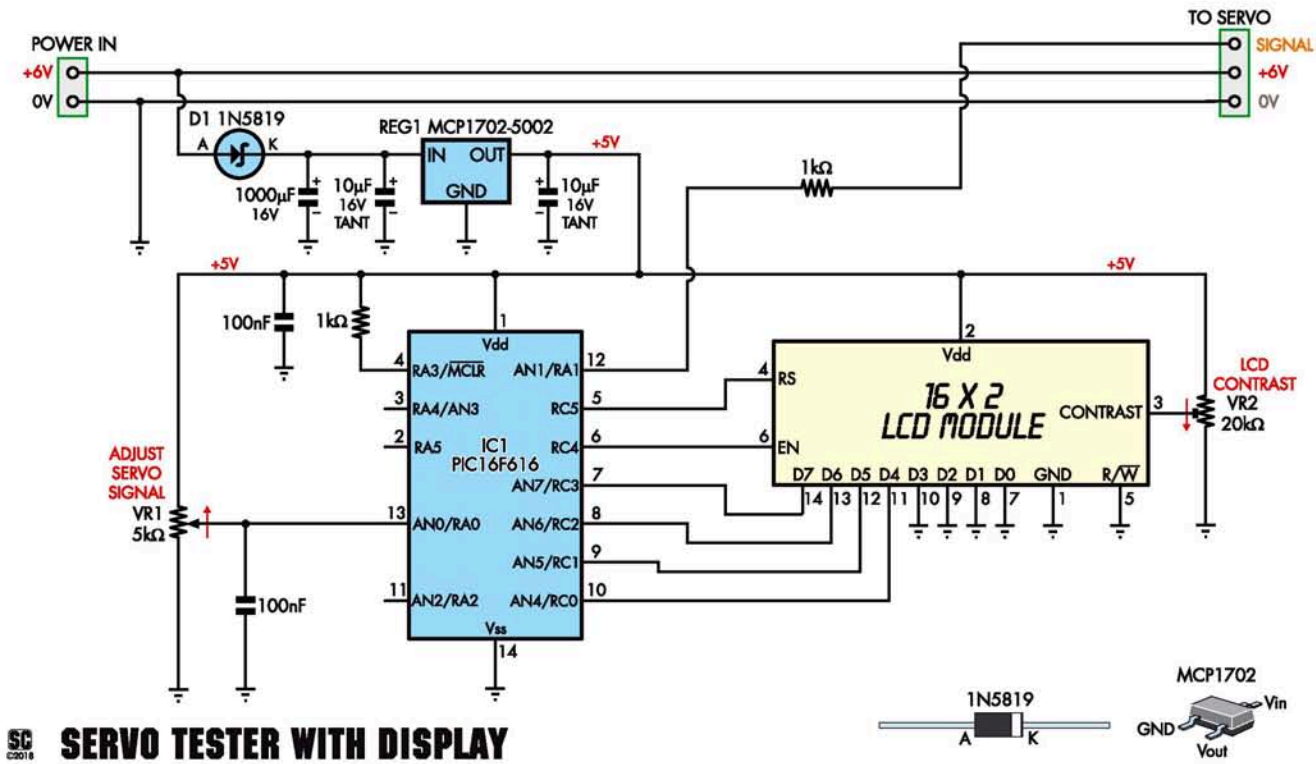
The BASIC source code ("ServTsT2.BAS") can be downloaded from the SILICON CHIP website, along with the corresponding compiled HEX file.

If modifying the source code, you will need the PicBasic Pro 3 compiler to create the HEX file. The HEX file can be loaded into the PIC using a range of PIC programmers, including the PICkit 3.

Finally, note that if you have a bench supply and DSO with built-in waveform generator, they could be used to do a similar job.

Set the bench supply to 6V output with current limiting to power the servo being tested and then use the DSO to generate and monitor the 50Hz/1.5ms control pulses and vary the pulse width to check the servo operation.

George Ramsay,
Holland Park, Qld. ($50)



SC ©2018 SERVO TESTER WITH DISPLAY

VINTAGE RADIO

By Associate Professor Graham Parslow

Astor 1952 Hybrid GP/PS Portable Radio

Astor's hybrid portable is a combination of the model GP's case with the later model PS circuit. It incorporates an RF preamplifier stage for excellent sensitivity, which is crucial for a portable radio. It's also notable for its 8-inch loudspeaker; quite large for a portable.

Sir Arthur Warner was a giant in the history of Australian radio. In 1922 he became a partner in a small Melbourne basement store that imported telephone equipment and radio parts. The outlet was the beginning of an industrial and commercial empire, best known by the Astor brand name.

Warner became chairman and managing director of Electronic Industries Ltd (Astor) in 1939. He died aged 67 in 1966, but packed what looks like ten lifetimes of parliamentary and industrial achievements into his time. Warner's Australian Dictionary of Biography entry can be read at siliconchip.com.au/link/aajs

Sir Arthur merits a mention because he was famed for his approach to containing costs and minimising waste. If Astor had a stock of 10kΩ resistors they would be used in a radio circuit that may have specified 20kΩ (as long as they worked).

The radio shown here looks like the Astor model GP introduced in 1948 but it is clearly date-stamped "21 FEB 1952". In 1952 the current Astor portable radio model was the PS which did away with the former discrete speaker grille fabric and used a moulded PVC mesh, integrated with the case.

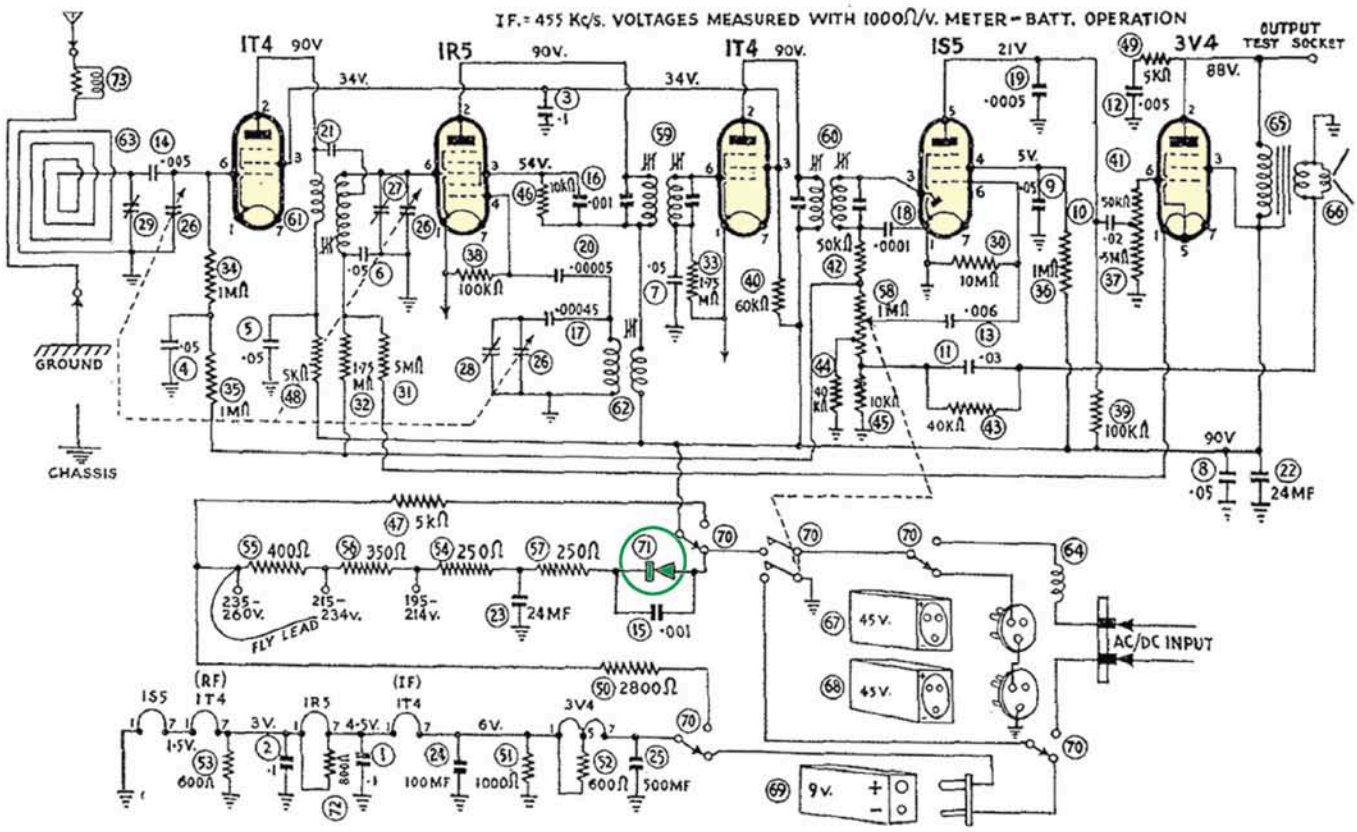
Incidentally, this case is not Bakelite but is thermoplastic (thermosoftening plastic). Because of this, heat generated from the internal components has caused quite apparent distortion.

But Sir Arthur apparently had some GP model cases that he was reluctant to discard, so this radio is a hybrid of the model GP case and the model PS circuit. Even so, his frugality did not mean cutting the quality of the components. For example, the speaker transformer in this radio is a large, high quality unit paired with the best speaker available at the time.

Why was it so easy to create such a hybrid? Again, it was a matter of being economical. The metalwork of this chassis is identical to other Astor portables, dating from the timber-cased 1946 model KP. In 1955 the metalwork for Astor valve portables was changed to support knobs on the front face.

Everything in this radio's circuit is true to the Astor model PS. It is a high-performance radio with an RF preamplifier stage.

This is immediately apparent from the three-gang tuning capacitor and is also indicated by the number 6 on the ARTS&P licensing decal (radios without an RF stage were licensed with number 5).



The Astor circuit has an number of interesting aspects such as the RF preamplifier (important for a portable set) and a tapped volume control to give a loudness effect (bass boost at low volume settings). But the ability to use 240VAC mains instead of batteries was a cheap and nasty approach since no power transformer was provided. Diode #71, highlighted in green, is a selenium rectifier stack.

Circuit details

The circuit starts with the internal loop aerial that is lattice wound on a plastic former, characteristic of a decade of Astor radios. Unlike the preceding model GP, the PS circuit has external aerial and earth connections terminating in sockets in the middle of the plastic lattice aerial former. The sockets are accessible from the back of the case.

The loop aerial is easily detached from the chassis by removing two screws. However, the connecting wires are short and it is not practical to work on the set until longer wires are patched in so the aerial can be moved further away on the bench. Fortunately, the tether to the 8-inch speaker is long enough to leave the original wiring in place.

By 1952 almost every Australian manufacturer of valve portables was using the same valve line-up as in this radio. RF preamplification is provided by a 1T4 pentode fed by the first tuned circuit, comprising the aerial coil and tuning capacitor.

As in many portables, there is no dial cord in this radio but a reduction gear allows the tuning knob to rotate through 270° while the tuning capacitor shaft rotates through 180° to provide easy and precise station selection.

The output of the 1T4 pentode is fed to the control grid, pin 6, of the 1R5 mixer-oscillator. Its grid bias is set by the AGC voltage derived from the diode in the 1S5 valve.

Since all the valves in this circuit have directly-heated cathodes, the overall grid-cathode bias for each valve is the difference between the grid potential (typically close to 0V) and the individual positive cathode voltage (between 0V and 9V) provided by the series heater string from the LT 9V battery.

The transformer coupling the RF stage to the 1R5 is housed in a square section aluminium can identical to the subsequent IF transformers (all three cans are on top of the chassis). The small local oscillator coil is under the chassis, close to the 1R5 valve, and feeds into pin 4 of the 1R5.

The intermediate frequency is 455kHz and the circuitry around the 1T4 IF amplifier is conventional.

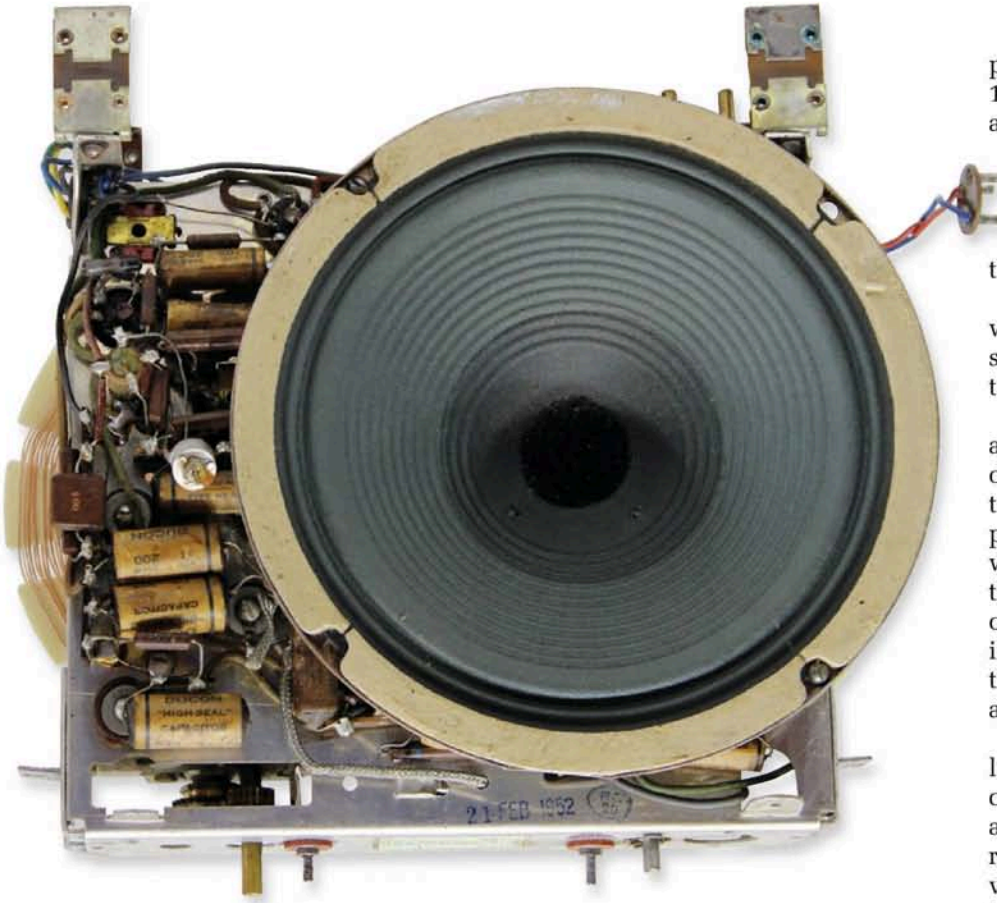
The 1S5 diode-pentode demodulates the RF signal (the diode's anode is at pin 3) and the resulting audio appears across the 1MΩ potentiometer and is fed to the control grid of the pentode section at pin 6. So the pentode in the 1S5 functions as an audio preamplifier.

The DC component of the demodulated audio signal to the volume control also becomes the AGC voltage to be fed back to the grid of the 1T4 RF preamplifier and the 1R5 mixer-oscillator.

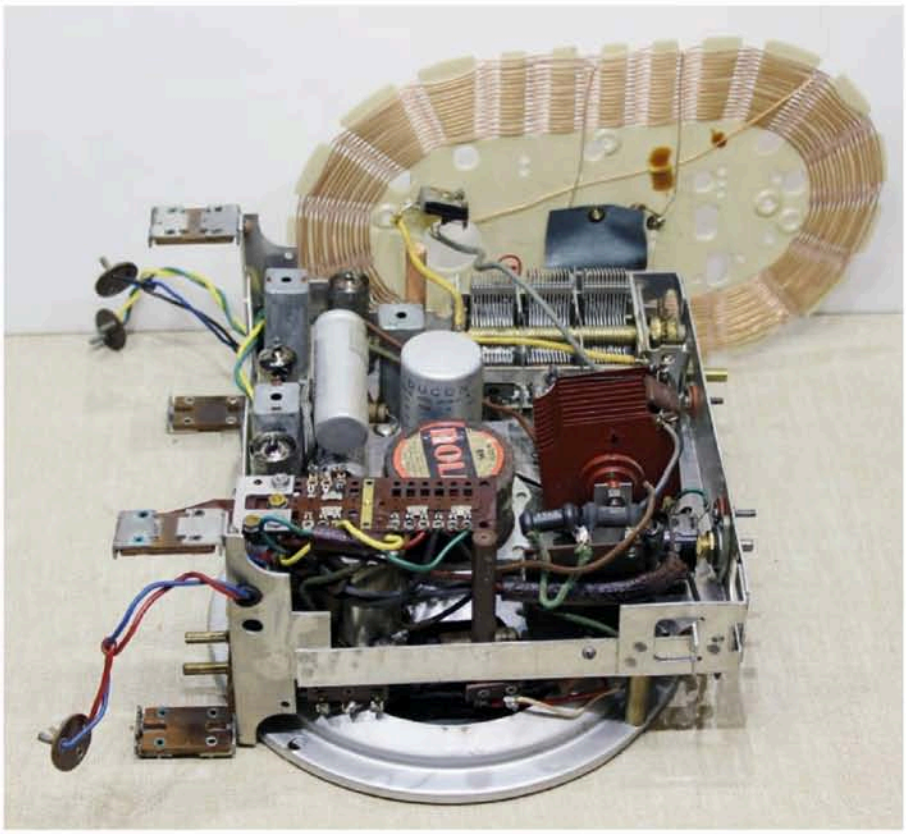
Loudness control

The output from the audio preamplifier's plate is fed to the grid of the 3V4. This pentode drives the single-ended transformer-coupled output stage and loudspeaker. Negative feedback is applied from the transformer's secondary winding to the bottom end of the 1MΩ volume control potentiometer.

But the main reason for this feedback is not to simply reduce harmonic distortion in the preamplifier and out-



The original 8-inch, 13Ω loudspeaker in the set is in very good condition.



This view of the chassis reveals the two brass prongs (lower left-hand corner) for the 240VAC input. That multi-pole switch in the foreground has live 240VAC present when the mains voltage is applied.

put stages. Have another look at the 1MΩ volume control (#58) which has a tap on it connected to the chassis via a 40kΩ resistor (#43). This provides a degree of bass boost at low volume settings, ie, when the wiper is on the section of the element between the fixed tap and chassis.

In a normal loudness circuit you would expect to find a capacitor in series with the 40kΩ resistor from the tap connection.

So how does the bass boost come about? That appears to be a function of the negative feedback connection to the bottom of the volume control potentiometer and its interaction with the .03µF capacitor shunting the 40kΩ feedback resistor from the output transformer's secondary winding. Backing up this notion is the fact that the 40kΩ/.03µF RC network has a +3dB corner frequency at 100Hz.

In any case, it is unusual to find a loudness control in a valve radio circuit, particularly a portable set such as this one. Loudness controls were reasonably common in higher-end valve radios and stereo amplifiers but typically they did not provide loudness compensation at low volumes (ie, bass and treble boost) but bass boost only.

The 3V4 output valve is capable of sending 250mW of audio to the speaker. This is fine for most listening situations when coupled with the high-efficiency Rola model 8M speaker.

AC & DC supplies

In common with many portable radios of the day, this Astor portable could be run from its batteries or the 240VAC mains supply. In fact, this radio can work from high voltage AC or DC mains, as well as batteries.

Two 45V batteries provide the 90V high tension rail and a 9V battery provides current to the series connected valve filaments, as shown on the circuit diagram. A switch accessible at the bottom selects battery or mains power. On-off is linked to the volume control.

However, while other portables of the time usually had a mains transformer, this set is transformerless and that means that, depending on the house wiring and the wiring of the input plug, the chassis could be operating at the full 240VAC potential.

In other words, if you have access to the chassis for repairs or alignment,

you are working in a potentially lethal situation. In this situation, you really should connect the set via an isolation transformer.

The mains input socket is at the bottom of the case and as can be seen there is no possibility of polarisation (both pins are the same) and if there were, that would not prevent the chassis from becoming live if the Active and Neutral wires were swapped.

The incoming mains supply is fed to a selenium rectifier stack, ie, it is a half-wave rectifier. The stack comprises ten elements meaning that any single element rectifies only 24V AC. This is close to the peak inverse voltage limit of selenium diodes.

The DC produced by the selenium rectifier (when new) would have been about 270V, allowing for the 5V or so of forward voltage drop for each element in the stack. That voltage is then progressively reduced by a series of wirewound resistors to produce the 90V HT and a further dropping resistor to produce the 9V for the series-connected directly-heated cathodes of the five valves.

Selenium rectifiers were a significant improvement on valve rectifiers when they were introduced, especially in portables because they needed no heater current and their forward voltage is considerably less than a valve diode at the same current. However, once silicon power diodes were introduced, they quickly rendered selenium rectifiers obsolete.

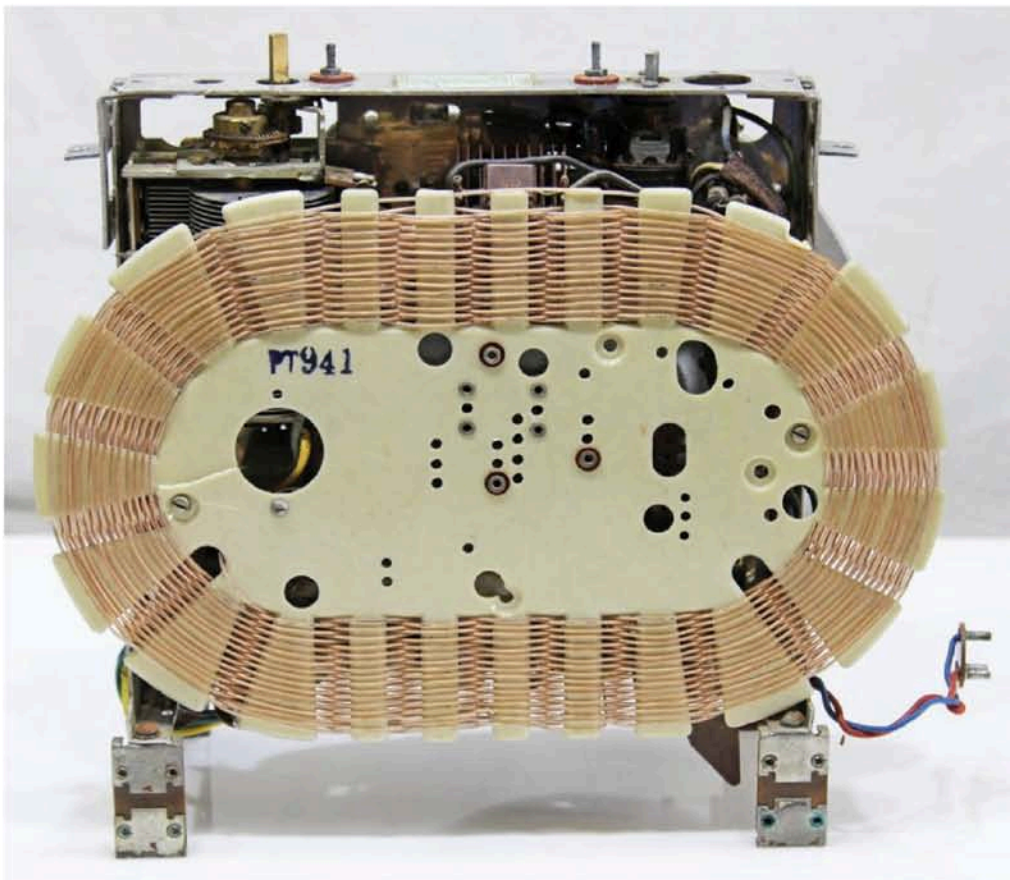
Editor's note: regardless of which way you look at it, the mains input to this portable set is dangerous. Apart from the chassis having high voltages present, if the mains is applied and the radio is turned on with the 3V4 valve out of its socket, the voltage across all the electrolytic filter capacitors in the circuit will be quite high and will probably cause immediate failure.

The selenium rectifier in a 66-year old circuit would also be suspect and likely to fail, with the risk of fire. We would strongly recommend that the 240VAC terminals in the recessed socket be removed to avoid any possibility that someone might attempt to power the set from the mains.

The restoration

This radio was purchased some time ago at an auction and had been stored on an upper shelf in a shed for some years.

Before restoration the cabinet was in a unkempt state with a tear in the plastic at the lower left-hand corner.



The lattice-wound loop aerial gives good signal pickup. External antenna connections are provided on the rear of the cabinet.

Then a possum discovered that she could nest with her joey a bit further along that shelf on a comfortable mat of bubble wrap and other packaging. The possum entered by way of a small gap between the wall and roof that led to the shelf. I decided to be tolerant at first; after all, they looked so cute.

Then the radio was knocked off the shelf but it fortunately had a soft landing. Then possum smells became evident and other objects were dislodged, as the possum explored the environment.

Enough was enough; the hole was blocked. Rather than put the set back on the shelf, I decided that it was the next candidate for restoration.

The cabinet was quite grubby and had a tear in the plastic at the lower left corner. This was patched with Araldite and a missing Astor swan badge was replaced from my spares bin.

The aluminium base-plate had been corroded by batteries left in the radio probably decades ago. After a thorough clean the plate was painted with acrylic silver paint to make it presentable. Little of that plate is normally seen anyway.

Removing the chassis is straight forward. The knobs at the top are removed by loosening grub screws. The yellow plastic dial plate requires only two nuts that hold it to the chassis to be removed. Then two screws at the sides of the chassis can be removed to let the chassis slide out.

All the components looked intact. The first operation was to clean the pins of each valve. Experience has shown that with near certainty one or more valves in portables will not function due to pin-socket corrosion (oxide-creep).

Bench power supplies were hooked up to the battery plugs. A good sign was that the 9V supply drew 52mA, indicating good connection of the series-connected valve filaments.

Ramping up the high tension initially showed much higher current than expected, but the current decreased with time. This was due to the electrolytic filter capacitors reforming their dielectric layer.

After some time the voltage reached 90V at 5mA but the radio was dead. The current should have been close to 10mA.

Using a signal tracer to check for tuned stations at the volume control produced an absolute zero. Both the RF and audio sections were dead. So I focused my attention on the audio section and fortunately, the speaker and output transformer checked OK.

I then found that the 20nF coupling capacitor from the 1S5's plate was leaky and this brought the 3V4 grid to +20V.

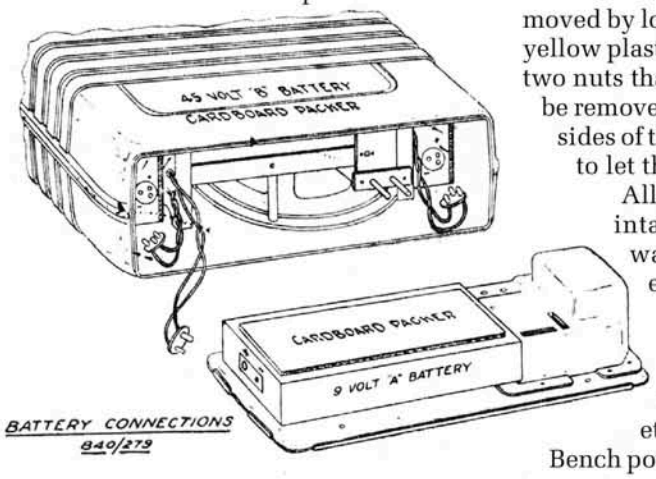
Normally this would cause excessive current drain on that stage but oddly, the HT current drain remained low after the capacitor was replaced, bringing the 3V4's grid back to 0V.

(In fact, as shown on the circuit, the series heater connections mean that the negative bias to the 3V4 grid is arrived at because the directly heated cathode is connected to the positive terminal of the 9V battery connection, ie, the grid is -9V with respect to the cathode.)

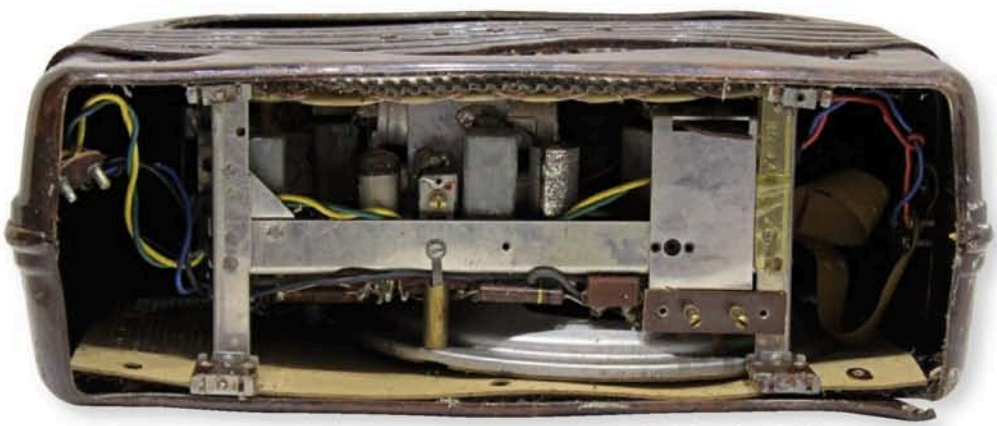
Audio from a signal generator now came through the speaker when injected into the 3V4's grid (pin 6) but nothing came through when audio was injected into the 1S5 diode or grid.

Pin 4, the screen of the 1S5 measured 11V instead of the 5V shown on the circuit although I will come back to that point. The 50nF screen decoupling capacitor was found to be leaky and the screen voltage limiting resistor was around 10MΩ; not 1MΩ as shown on the circuit.

Replacing the defective resistor and capacitor restored function in the 1S5 and signal injected at the 1S5 diode now responded to the volume control as expected. So the audio section was now functioning.

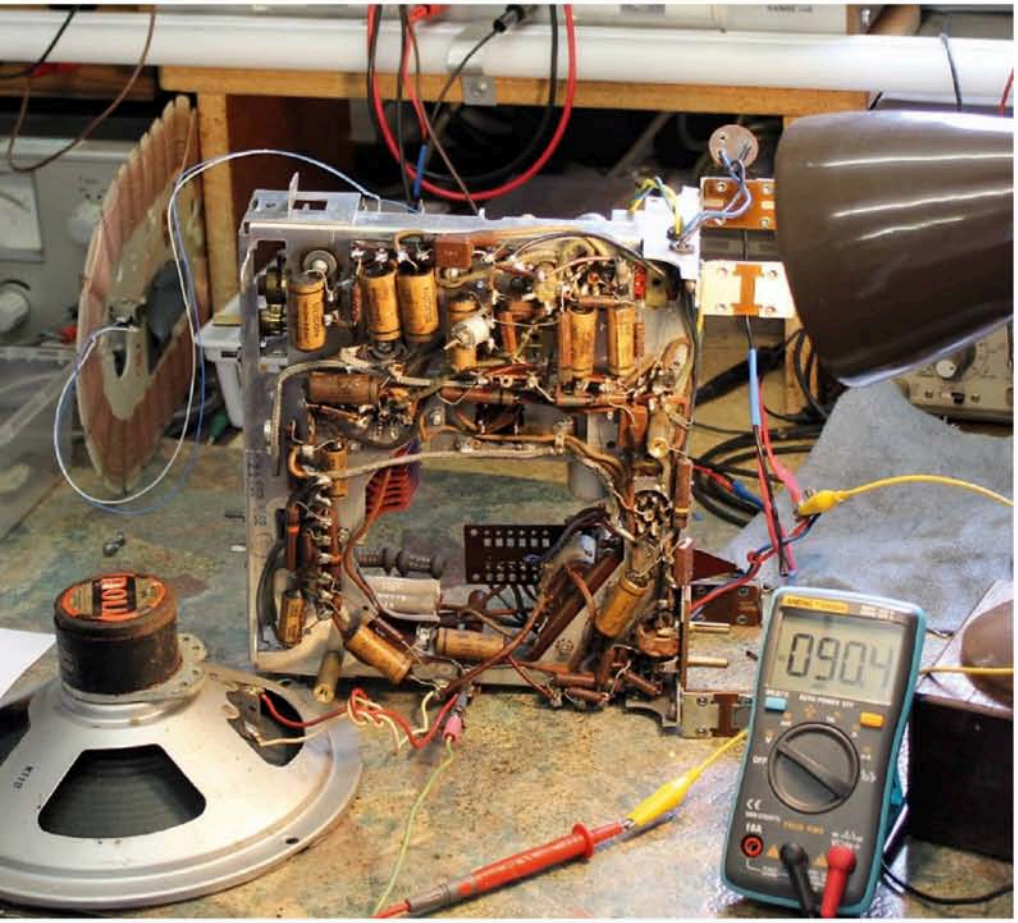


These two views of the underside of the show the battery compartment and the chassis base-plate together with the recessed 2-pin socket for the 240VAC mains input. The cover for the socket is missing.

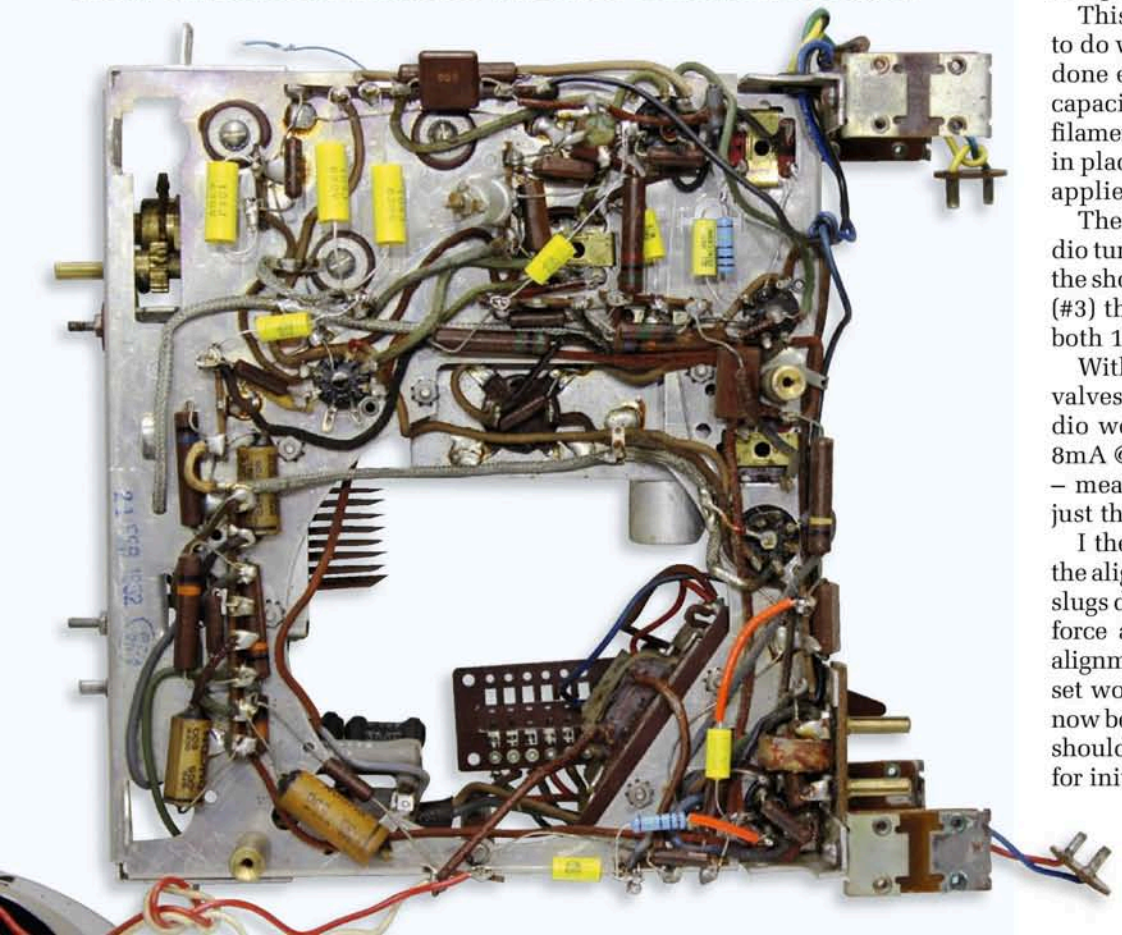


Voltage measurements

Now back to that point about the voltage on the screen of the 1S5. All the voltages shown on the circuit are



Most of the wax-impregnated paper capacitors on the unrestored chassis (above) needed to be replaced due to high leakage. A few of the carbon resistors had also gone high in value and so were replaced. Since there's no power transformer, the chassis can become live if the Active and Neutral connections are swapped.



what would have been found with 1000 ohms/volt meter.

Such a low meter sensitivity was normal in those days but the screen voltage was actually much higher, even after allowing for the very small screen current that would normally flow. In fact, measurement with a modern digital multimeter with an input resistance of 10MΩ gave a value of 50V.

While the audio stages were now working, there was still no RF output. All plate voltages were correct except the 1T4 preamplifier valve which was sitting at 9V, not 90V.

The 50nF capacitor shown as component 5 was down to 30Ω and was pulling the HT low. Fortunately the 5kΩ decoupling resistor (#48) survived being shorted to earth. The plate came back to 90V with a replacement capacitor.

Then the first IF transformer (#59) was found to have an open-circuit secondary. It was replaced from an Astor chassis I had on the spares shelf. The associated 50nF capacitor and 1.75MΩ resistor were also replaced; the resistor had gone high in value.

A signal generator injecting modulated 455kHz still did not produce any detectable output on an oscilloscope along the chain of RF components.

This was baffling until I decided to do what I probably should have done earlier and replace all paper capacitors in the main circuit (the filament circuit capacitors were left in place as they have less than 10V applied to them).

The final key to restoring the radio turned out to be replacement of the short-circuited 100nF capacitor (#3) that decouples the screens of both 1T4 valves.

With no screen voltage both 1T4 valves were dead. After that, the radio worked as it should, drawing 8mA @ 90V. My take-home lesson – measure all valve voltages, not just the plates.

I then set the radio up to check the alignment. However, the tuning slugs did not move under moderate force and rather than persist, the alignment was abandoned. Still, the set works reasonably well and has now been moved to a display shelf. I should probably thank the possums for initiating the restoration. SC

PRODUCT SHOWCASE

LEDs on surfboards a shark attack deterrent?

OK, so it's not a new product – yet – but it could be within a couple of years if research being conducted by Sydney's Macquarie University proves to be as successful as first thought.

Researchers have been conducting extensive research in the world capital of great white shark attacks, South Africa, where they report that putting LEDs on the bottom of surfboards has so far proved to be "100% successful" in preventing great white attacks.

The theory is that the flashing LEDs on the surfboard break up the tell-tale silouhette of the board from underneath, convincing the shark that the board (and its rider, who is more often than not clad in a "seal" coloured wetsuit) is not their next meal.

However, the researchers warn that it is not simply a matter of putting flashing LEDs on the board – both the light pattern and brightness were important – some patterns simply did not work in deterring shark attacks.

However, when the team's seal shaped boards were towed into shark-rich waters, without the lights the great whites did not hesitate to attack. With the lights, no attacks occurred.

Professor Nathan Hart, who lead the research, said that the correct configuration of lights changes the appearance of the board and the shark no longer recognises it as prey.

He maintains that the LED-equipped boards worked better than the currently available electronic shark repellant systems.

Furbo remote dog camera keeps you in touch . . . and even feeds it!

It's one thing to remotely monitor your pooch on your smartphone while you're away . . . but now the Furbo goes even further. It lets you talk to your dog and remotely feed your dog treats if it is behaving!

Features include:

- Uses AI recognition technology
- 1080p HD camera features a 160° wide-angle lens, 4x digital zoom and infrared LED night vision for monitoring and clear pictures and videos
- Two-way audio – both hear and speak to your dog and give them the comfort of a familiar voice throughout the day
- Treat Tossing System – With the touch of a button on your app you can play with, and reward, your furry friend
- Barking Alerts – uses AI-recognition to deliver push notifications to your smartphone letting you know if your dog is barking
- Mobile App Connectivity – WiFi and Bluetooth capabilities, compatible with both iOS and Android, provides access from your smartphone, tablet, or Apple Watch.

Contact:
Furbo.com
Web: shopau.furbo.com/

New MPLAB PICkit4 Development Tool

The new low-cost PICkit4 in-circuit programming and debugging development tool replaces the popular PICkit3 programmer, offering five times faster programming, a wider voltage range (1.2-5V), improved USB connectivity and more debugging interface options.

In addition to supporting Microchip's PIC MCUs and dsPIC Digital Signal Controllers (DSCs), it also supports debugging and programming for the CEC1702 family of hardware cryptography-enabled devices.

It is ideal for those designing in the 8-bit space, but it is also suited for 16- and 32-bit development, due in part to its 300 MHz, high-performance ATSAME70Q21B microcontroller. Faster programming time means better productivity during development.

This is especially important when designing with 32-bit microcontrollers with larger memory capacities.

Contact:
Microchip Technology Australia
32/41 Rawson Street, Epping, NSW 2121
Tel: (02) 9868 6733
Web: www.microchipdirect.com

Caterpillar's first solar plant in action on Australian soil

In a first-of-its-kind project combining solar and methane gas in an energy production farm, Energy Power Systems Australia (EPSA) has mounted 11,040 Cat PV solar modules on fixed-axis steel frames in the Adelaide foothills.

EPSA engineered, designed, constructed and commissioned the 1.15MW (AC) PV solar plant, which is utilising an unused portion of land next to the Uleybury Landfill site as a solar farm.

The PV solar modules are arranged into 46 power blocks each feeding a dedicated 25kW (SMA) inverter.

Contact:
Energy Power Systems (Aust)
227 Wellington Road, Mulgrave Vic 3170
Tel: (03) 8562 4100
Web: www.energypower.com.au

ASK SILICON CHIP

Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

Real-time monitoring for seismograph

I like the Arduino 3-Axis Seismograph you published in the April 2018 issue (siliconchip.com.au/Article/11030).

But I'd like to connect it up to a computer to give a full-time display. Can you tell me how to do that? (D. W., Smithfield, NSW)

- Line 463 of the Arduino sketch reads:

```
Serial.print(F("|XY|="));
Serial.print(xy_vector_mag);
Serial.print(F(",|Z|="));
Serial.println(z_vector_mag);
```

Change it to this:

```
Serial.print(xy_vector_mag);
Serial.print(F(","));
Serial.println(z_vector_mag);
```

This prints out the raw data, allowing the Arduino Serial Plotter to read and capture the data.

The Serial plotter can be opened by selecting Tools → Serial Plotter from the Arduino IDE. Set the baud rate to 115,200. This will give you a rolling, colour-coded plot of the horizontal and vertical components of vibration that are picked up by the Seismograph. It will still log to the SD card as before.

Using Arduino ECG board with PICAXE

I'm thinking of using the circuit of the Arduino ECG (October 2015; siliconchip.com.au/Article/9135) in a modified way for electroencephalography (EEG) measurements.

It would be great if there happened to be an 8-pin (or more) DIL connector for a PICAXE or other microcontroller. Do you have a version of the board with such a connector? (F. F., Perth, WA)

- That board is designed to plug into an Arduino Uno or compatible board which already contains a microcontroller (ATmega328P in the Uno).

If you wanted to use a different microcontroller such as a PICAXE, you would just need to make five connections via the existing Arduino headers. Those connections are shown in the circuit diagram on page 56 of the October 2015 issue and include ground, 5V power, the ECG signal, sensitivity switch position and sampling LED drive.

Incidentally, Jim Rowe is working on an EEG monitor (brainwave monitor) that uses similar principles to the ECG project you're querying. Assuming that it works as well as we are hoping, we will be publishing it later this year.

Safety concerns with Heater Controller

I have enjoyed your magazine since it started publication and am a long-term reader of most of the available electronic magazines since the late 70s but this is the first time I've felt the need to respond to something I've read in your publication.

From my reading of the article on the 230VAC Thermopile-based Heater Controller, the design floats the circuit on the high side of the mains supply and relies on the dielectric isolation of a standard single-turn potentiometer to separate this circuit from the earthed case.

We used to manufacture audio gear (many moons ago) and were always advised not to stress these components with more than 100V due to the wide variances in the manufacture of these parts and the fact that the standard pots use very cheap phenolic material which may not stand-up long term to high voltage differentials.

The gap between the rivet lugs on the pot and the case also seems small and depending on the riveting, might also cause safety issues. I read through the article and I feel it did not stress to the reader the voltage differences between the circuit side of the pot and the mechanical side.

I felt the design a least needs to have some isolation layer like a plastic sheet between the case and the pot lugs to isolate the legs and the lugs a bit more than just the heat shrink wrap on the three soldered legs.

I'm also a bit dubious about dropping mains voltages across one resistor (also in this design) regardless of wattage and have always used three or four in series to ensure against arcing or discharges.

Having single resistors doing this job seems to be creeping into designs because of size constraints but if you look at the design of switchmode type power supplies used in things like TVs, they still use several in series to avoid serious single point failures on the mains side of the circuit. You won't know the dielectric breakdown of something selected from a Jaycar or Altronics bin. (S. L., via email)

- We agree that all efforts should be made to ensure that components do not fail and that the project is safe to use.

The potentiometer used and specified is a 24mm type that has a 400V continuous rating (500V short term). Note that we do not use 16mm potentiometers due to their lower voltage rating. The 1W resistor is rated at 400V.

Silicon Chip (and *Electronics Australia*) have been using these types of components in live mains equipment for at least 40 years. All mains controllers that Silicon Chip has published have used these types of components, with the potentiometer secured to the case.

That includes the simple phase controllers from the distant past, using Triacs and Diacs for light dimmers. There have never been any problems that we are aware of where the potentiometer insulation has broken down and where the clearance between the potentiometer connections and case are insufficient. This includes projects that are still working after decades of use.

Our latest motor speed controller from March 2018 uses a similar circuit arrangement.

In the event that the potentiometer insulation or spacing to the case

introduces a breakdown to the case, the earthing of the lid and case maintains safety. But we are not aware of any such failures.

ADF4351 frequency resolution

Thanks for your great article on the 35MHz-4.4GHz Digitally Controlled Oscillator in the May 2018 issue (siliconchip.com.au/Article/11073).

I found it very informative and useful but when reading page 85, I was a bit confused regarding the frequency resolution of the DCO chip.

Since the chip contains frequency dividers (1/2/4/8/16/32/64), it would appear the frequency resolution would increases proportionally as the division ratio increases, or is it the loop filter that is controlling the frequency resolution for the module? (H. R., Mt Martha, Vic)

● The output frequency resolution for the ADF4351 is equal to the reference input frequency (REF_{IN}) divided by the modulus value and further divided by the output divider ratio.

Since the minimum reference input frequency is 10MHz, the maximum modulus value is 4095 and the maximum output divider ratio is 64, the best possible frequency resolution is just over 38Hz.

But that arrangement would result in a rather limited output frequency range.

The frequency resolution steps are considerably coarser for higher output frequencies. More realistic values for the resolution during normal use would be in the range of 5kHz-1MHz.

Tiny microcontrollers now available

I've been a reader of SILICON CHIP for many decades. Every issue contains something to tickle my fancy.

When I turned to the back cover of your March 2018 issue, I saw the Microchip advertisement and was quite gobsmacked to see that some of their MCUs are as small as 1.9 x 2.4mm.

Wow! That sure is small. How are they connected to a board? Would you consider writing an article about these tiny miracles? I'd be fascinated to see more information about them and how they are implemented. (K. W., Newport, Vic)

● Chips that size have been available for some time now. They're usually flip-chip style BGA devices in packages known as "chip-scale"; for example, WLCS packages.

Part of the reason that this is possible is that modern processor manufacturing techniques enable the creation of minuscule transistors, so the entire processor can fit in a tiny area (typically under one square millimetre).

In fact, the largest part of a microcontroller silicon die these days is usually the transistors that are used to drive the output pins, since they need to be able to source/sink a reasonably substantial current (25-50mA), which is far more than the microscopic transistors that provide the logic functions are capable of.

They are soldered to the board like just about any other leadless package, either via an array of solder balls supplied pre-soldered to the chip ("ball grid array" [BGA]) or using tiny blobs of solder paste between the chip and board, which are then melted via infrared heating ("land grid array" [LGA] or similar).

There is some information on these tiny packages at Wikipedia. See: en.wikipedia.org/wiki/Chip-scale_package

Success troubleshooting Super-7 AM Radio

I recently built your Super-7 AM Radio and had trouble getting it to work, so I wrote in asking for your advice. Your response was quite useful and I am now happy to report that it works. I am 88 next month and am a

GPS module has a strange configuration

I just finished building the 6-digit High-Visibility Clock project that was published in the December 2015 and January 2016 issues (siliconchip.com.au/Series/294). I am using a VK2828U7G5LF GPS module. Construction was straightforward and I didn't encounter any problems.

But after powering it up, it only displays 9P5 ("GPS"?) and the last two digits are sort of rotating.

It never actually displays a time. The red power LED on the GPS module is on and the two green LEDs on the module are blinking every second. The GPS supply voltage jumper is set to 3.3V.

I reset the clock several times (and discharged the super cap with a resistor) but it didn't change the behaviour. I can go through the menus with the two pushbuttons and all seems to work, but no time is displayed. I checked with a CRO and there are good 3V pulses on pins 9 & 24 of IC1. I purchased the PIC from your shop; I did not program it myself.

I tried swapping the GPS module for an ESP-01 module, as per your article on the Clayton's "GPS" Time Signal Generator in the April 2018 issue (siliconchip.com.au/Article/11039).

It logs onto my WiFi network with no problems and the clock then works fine and displays the time. The time displayed is about five seconds out, by my reckoning.

I connected both the GPS module and the ESP-01 to a USB/serial converter and plugged it into my PC to log the output data from each.

The GPS unit is producing only GPRMC data blocks, whereas the ESP-01 puts out a whole lot more (GPRMC, GPGGA, GPGSA and ESP82). Does the GPS module need to be re-configured? (R. L., Gooseberry Hill, WA)

● That's odd. We have never seen a VK2828U7G5 module that only produces GPRMC sentences. All the ones we have tested produce the GPGGA and GPGSA sentences too. That is definitely why the clock is not showing the time. It is waiting for the GPGGA sentence so that it can verify that the module has a satellite lock.

You should be able to reconfigure the GPS module to produce GPGGA sentences but we don't understand why it isn't doing so by default. You may need to use the "u-center" Windows software to do this (and may work on Linux with Wine). The information at this link may help: siliconchip.com.au/link/aajv

novice; I guess I must still have something up top!

It turned out that the primary winding on the oscillator coil was faulty, with an open circuit, and also the PCB copper track between the oscillator and the collector of Q1 was open-circuit; I had soldered from the bottom but it was not connected through to the top. I soldered the top side of the pad and then it started working.

Finally, how did you attach the tuning knob and clear plastic ring to the tuning gang? (R. W., Menora, WA)

● It's good to hear that you got it working. The clear plastic dial is designed to be a press fit onto the knob supplied with the tuning gang.

But since the knobs may vary slightly in diameter, we made the hole in the dial just a tiny bit smaller than the outer diameter of the knob. That means you may need to very gently file the inside of the hole in the clear dial until it's just large enough to press the knob into.

You could also glue it (eg, using super glue) but we found the friction fit was good enough to hold it firmly on our prototype. You will, however, need to glue the part of the knob which sticks out to the clear dial. We suggest you use clear silicone sealant behind the knob as this will allow you to pull it off, in case you ever have to take the radio apart in future.

Questions about revised Anti-Fouling unit

I built the revised Marine Ultrasonic Anti-Fouling unit as described in the May and June 2017 issues of SILICON CHIP (siliconchip.com.au/Series/312) from a Jaycar kit.

All went well testing the power supply, inserting the microprocessor and attaching the ultrasonic transducers to the hull of my 5m aluminium runabout.

I decided to build and install the two-channel version even though the single-channel version is regarded as adequate for boats up to 8m.

On powering up, the green power LED came on for a few seconds, then went off and the red fault LED started to flash. The problem did not recur when I uncoiled the excess cord to the transducers which prompted me to wonder under what conditions the micro is programmed to shut down and cause the red fault LED to flash. Knowing this would greatly help with troubleshooting.

I have since re-coiled the excess cord to the transducers and the unit performs normally so clearly coiling was not the cause of the problem; it remains a mystery to me.

Would the impedance of the twin core wiring to the transducers filter out the high-frequency components (ie, harmonics) of the AC square wave and degrade the performance of the transducer, even if there was no significant impedance at 20-40kHz (ie, the fundamental frequency)?

I think it's a good idea to have a fuse close to the positive of the battery if the unit is installed in an aluminium or steel boat (where the hull is connected to the battery negative).

The fuse in the unit will only protect against a short in the unit itself. On a similar note, I would put a solar panel fuse in close to the battery positive, not close to the panel.

Finally, medical ultrasound in the MHz range is regarded as safe, even for an unborn foetus. How then is 20-40kHz ultrasound lethal to marine life? (Dr. P. K., Warrawee, NSW)

● The Anti-Fouling unit shuts down when the low ESR capacitor(s) fail to charge initially or if they are leaky. In your case, it seems the capacitors required an initial charge before achieving an acceptable leakage level, allowing the fault LED to stay off subsequently.

This was likely due to them "reforming" after not having voltage applied for a long time and it's quite normal.

Virtually all of the Anti-Fouling projects that are built use the length of wire supplied by Jaycar for the ultrasonic transducer connection. We do not know the lead specifications of the pre-potted transducer supplied by Jaycar but lead losses do not appear to affect the success of the ultrasonic anti-fouling on the hull.

In general, distributed lead capacitance and inductance would filter out the higher harmonics from the square wave produced by the transformer.

That is not necessarily a bad effect as the transducer is most efficient around resonance, ie, at the fundamental frequency. Most ultrasonic loss from the transducer is due to dampening from the potting within the transducer housing and the attachment to the hull.

As far as we are aware, the ultrasound prevents algae growth on the hull and so this discourages any other form of marine life attaching to the hull as there is no food source. It does not produce a lethal zone for marine life.

Induction Balance Metal Detector wanted

I have just finished building the SILICON CHIP Theremin design from the January 2018 issue (siliconchip.com.au/Article/10931), a most enjoyable project but learning to play tunes is a challenge. I'm now ready for my next challenge.

Have you considered designing a pulse induction metal detector for gold/treasure locating?

Powered by a LiPo battery pack, I believe this would be a very popular project and could be used at the beach, or, in many cases, by the growing number of (grey) nomads like me wandering around the inland parts of this great country. I might even find a small nugget or two. (D. L., Blaxland, NSW)

● We published an Induction Balance Metal Locator design in the Circuit Notebook section of the March 2018 issue (siliconchip.com.au/Article/10999).

It may not be what you are after as there is no PCB design, just a circuit and some software.

We don't have plans at present to design a pulse induction metal locator but we might be convinced to do so if there was sufficient reader interest.

Clock not responding to remote control

I recently assembled your High-Visibility Clock (December 2015 & January 2016; siliconchip.com.au/Series/294). I am very pleased with this project, however, I cannot get the remote control to work. I am using the Altronics remote as suggested. The remote seems to be working fine (fresh batteries and checked with a digital camera).

I can occasionally get a response with the remote hard up against the sensor so it appears to be a sensitivity issue. The right-hand side decimal

point which indicates a signal from the remote is always weakly illuminated but it does flash when a command is received. I would be grateful for any hints on this problem. (J. G., Christchurch, New Zealand)

● Since you say that "occasionally get a response with the remote hard up against the sensor", you obviously are using the right remote control code.

There are a few reasons this may happen. The receiver may be faulty, you may have a lot of infrared interference in the environment or there may be a lot of electrical noise affecting the receiver.

Firstly, try moving the clock to a different location and switching all the lights off and see if it responds reliably. If so, that suggests you may have some IR interference, possibly from a compact fluorescent light in the vicinity.

If it still doesn't work, try a different power supply, ideally a regulated bench supply.

The infrared receiver has a supply filter consisting of a 100Ω resistor and 100µF capacitor which should prevent electrical noise from affecting it but a particularly high level of noise may still be able to get through. Try soldering a 1µF ceramic capacitor across the 100µF electrolytic.

If that still doesn't help, you may need to replace the infrared receiver. It's possible that the one you used is operating at a significantly different frequency than the transmitter or it's just faulty.

SC200 with a lower voltage transformer

An *EPE* Magazine reader asked the following related question regarding the low supply voltage version of the SC200 Amplifier (January-March 2017; siliconchip.com.au/Series/308):

"In the third article, it is explained that a lower voltage 30-0-30V transformer can be used with the following component changes: reducing Q7's collector resistor to 15kΩ and reducing the two collector resistors of Q6 to 4.7kΩ each."

"I want to use a slightly lower voltage transformer (25-0-25V). Will the component changes work with my lower voltage transformer or will I need to reduce the resistances further and change any others?" (A. W., Wimborne, UK)

● To be safe, you should scale the component values down further. You would expect DC supply rails of around ±35V DC from a 25-0-25V transformer. So the 22kΩ resistor should be reduced to 12kΩ and the 6.8kΩ resistors to 3.9kΩ.

It's the 22kΩ resistor which is the most critical as this needs to supply the correct current to Q7 so that Q8 can generate a near rail-to-rail swing at the output without burning out quickly if the output is shorted.

CLASSiC-D amplifier voltage check query

I assembled two of the KC5514 kits from Jaycar, based on your CLASSiC-D Class-D amplifier project in the November and December 2012 issues (siliconchip.com.au/Series/17).

As per step 6 of the testing instructions, the CSD voltage should be 5.6V but both modules gave readings of 5.0V. The only way the voltage could be 5.6V is by reversing IN4148 diode D5 as the voltages either side are 5.0V and 5.5V. V_{SS} measures -5.5V. Please advise. (J. H., Melbourne, Vic)

● The voltage at CSD is set by the voltage at V_{AA}. If V_{AA} is 5.6V then CSD should be close in value to that. If it

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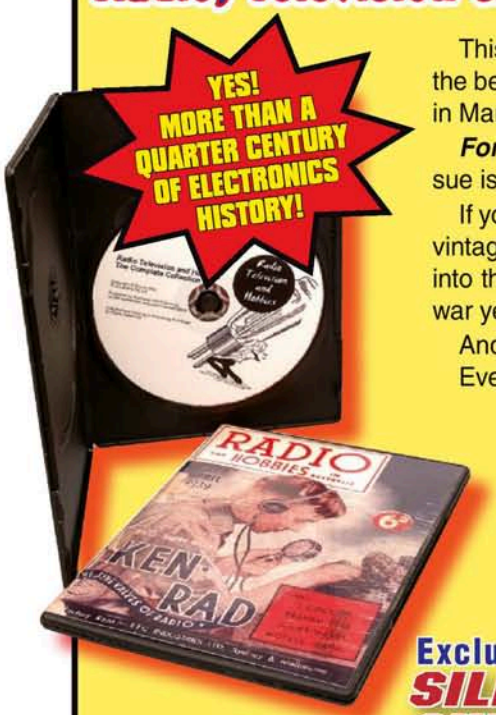

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is a little lower then there is probably a small amount of current leakage through the 10µF capacitor connecting between CSD and V_{SS}.

The 5V reading you obtained is within the acceptable range and this will not cause the amplifier to shut down. That only will happen when the SD terminal is taken low toward -5.6V via the 100Ω resistor, D5 and Q9.

Note that any reading on the cathode (k) of diode D5 is meaningless if the amplifier is not shut down (ie, when Q9 is switched on) as the cathode is essentially open circuit and the voltage will just be due to diode current leakage and noise.

Compact Frequency Meter not working

I have built the Compact 8-Digit Frequency Meter design from the August 2016 issue (siliconchip.com.au/Article/10037) using an Altronics kit, Cat K2610.

Unfortunately, it does not function correctly. When switched on with no probe connected, it displays random numbers, sometime in kHz and sometime in MHz. After a while, it settles down and displays 0.

I built a frequency source with a 555 timer which provides a square wave at 1432Hz. I measured it with the SILICON CHIP LED Strobe & Tachometer (August-September 2008; siliconchip.com.au/Series/52) and another frequency meter. They measured 1432Hz and 1435Hz respectively.

When I try making measurements with the 8-Digit Meter, it displays random figures, mostly around 4.5kHz or MHz, regardless of what the meter is connected to. I connected the photo interrupter board to it and the readings are the same. Stepping through the possible settings makes no difference.

Of course, I re-checked the circuit board and soldering. I also replaced the PIC chip but that didn't fix it. Any help would be appreciated. (H. M., Bowral, NSW)

- It would seem there is an open-circuit connection in the signal path from the input through Q1, IC1, IC2, IC3, IC4b or IC4a. Trace the signal from the input at CON1 to the output of IC4a.

You could use one of the other frequency meters you mentioned. You should be able to get a reading of 1432Hz at the various stages, ie, pin 3 of IC1, IC2 and IC3 and bursts of signal at pins 3 and pins 7 of IC4a.

Alternatively, there could be an open connection from pin 1 of IC5 to pin 1 of IC4 or from pin 6 of IC5 to pin 6 of IC4b. That can be checked with a multimeter on the ohms range with power switched off on the 8-Digit Frequency Meter.

Barking Dog Blaster current is wrong

I have built the barking Dog Blaster design that was published in the September 2012 issue (siliconchip.com.au/Article/529). When I power it up, the LED lights as expected, responding exactly to instructions regarding the start switch. The test tone sounds nicely.

All seems well, except that the unit only draws about 40mA normally, 60mA when the test tone is sounding. You have specified a 1.5A supply so I suspect that something is amiss. 60mA does not seem like enough to blast the offending dog! (A. F., Salamander Bay, NSW)

- The unit should draw 350mA during the peak burst period when driving one piezo tweeter. That rises to a peak of 1.4A for four tweeters. If you look at the Scope3 waveforms in the arti-

Correct orientation for SMD semiconductors

I got two kits for the article on installing USB charging points in your car directly from your office after that article appeared in the July 2015 issue of SILICON CHIP (siliconchip.com.au/Article/8676). Both the kits and the magazine have been on the back of my bench since then and I have finally gathered the courage to tackle soldering the SMDs.

I have also purchased a hot air rework station and am keen to try this. I can set the hot air temperature, is there a maximum air temperature I should not go above?

In your article on page 40 of the July 2015 issue, there is a caution to get the orientation right on REG1, TVS1 and D1. Looking at REG1 in real life (the RT8299A IC), I can't distinguish which pin is pin one. I am used to seeing a semi-circle indent on the pin end of through the hole ICs but can't see anything on this one.

Similarly, on the real TVS (SMAJ15A), nothing appears to show the polarity and the same goes for D1 (SK33A). I am used to seeing a white ring on one end of the through-hole components as shown in Fig.7.

Can you please help me to establish pin one on REG1 and the direction that the two other components should be orientated on the PCB. (R. K., Auckland, NZ)

- Your hot air rework station certainly would be handy for soldering IC1 with the thermal pad on its underside. Our station does not have temperature markings but simply a scale from one to eight and we have it set at the halfway mark (between four and five).

On a small device like IC1 and with such a small PCB, once the hot air is up to temperature, it should melt the solder paste in under ten seconds. If it's taking longer than that, you would probably want to turn it up a bit.

Initially, it's best to move the hot air around the periphery of the IC rather than just aim it at one point as this helps heat up the PCB but more importantly, it should prevent burning of the solder mask if the air is too hot.

There is a dot indicating pin 1 on the top of the RT8299A package but it is quite faint. There is also a bevelled edge which should be easier to detect.

Look at the IC package end-on and you should see that the top surface on one side has its corner "cut off" and the other is not. Pin 1 is on the cut off side. The PCB overlay diagram (Fig.7) indicates where the bevelled edge goes.

Both the SMAJ15A and SK33A have a stripe across the top at the cathode end. Looking at the photo of the board next to Fig.7; the stripe on the SMAJ15A is harder to see but they should both be visible under strong light with some magnification.

cle, the bursts can be seen separated by a wide gap. The duty cycle for the bursts is only around 10%. This makes the average readings much lower (ie, around 140mA when operating with four tweeters).

If you are measuring a quiescent current of 40mA when the unit is not operating then something is wrong as this should be 180µA (ie, 0.18mA). Check that the correct regulator has been used and that all components are correctly placed.

60mA does seem low for the operating current but it really does depend on the way you are making the measurement. A multimeter will only show an averaged current and is not likely to be accurate for a device like this, with a low operating duty cycle.

Component values for simple mains supply

I have seen a similar power supply circuit in many different mains-powered devices that I've opened up, such as sensor lights. They have a capacitor and resistor in series between one of the supply pins (Active or Neutral) and a bridge rectifier which charges up a filter capacitor that has a zener diode connected across it.

I think this circuit could have other uses from time to time, for running low-drain DC devices from mains, such as LED pilot lights and the like. Of course, the device would have to be fully insulated with no user-accessible parts and be a fixed device, not, for example, a portable radio, which would need a proper PSU to run it.

If we know the voltage and current requirements of the load, is there a formula to work out the values of the capacitor and resistor which are wired between the incoming mains and the bridge rectifier? Also, do we need a resistor on the load side of the bridge rectifier? I looked online but couldn't find a satisfactory answer to these questions. (B. P., Dundathu, Qld)

● This is a very common type of supply for low-power mains-powered equipment and we've used it or a variation of it many times in our project designs; most recently, the related Full Wave Motor Speed Controller (March 2018; siliconchip.com.au/Article/10998) and Thermopile-based Heater Controller (April 2018; siliconchip.com.au/Article/11027) projects by John Clarke.

You don't need a resistor between the bridge rectifier and filter capacitor/zener since the series capacitor on the mains side of the bridge rectifier provides the same function.

One way to determine the required values of these components is via simulation (eg, LTspice) and indeed, we covered this very topic in the tutorial starting on page 38 of the June 2017 issue ("LTspice – simulating and circuit testing, Part 1" – siliconchip.com.au/Article/10669).

But you can calculate the approximate values required if you know how much current the load will draw at the target voltage and the maximum inrush current the parts can withstand.

The series resistor exists primarily to limit the inrush current and the peak current will basically be 325V (ie, the peak mains voltage) divided by its value. So if you want to keep the inrush current under say 1A then a 330Ω resistor would be appropriate.

The series capacitor must be an X2 or similar type which is rated to be connected directly across mains conductors. If you know that the mains supply is nominally 230VAC and your load needs say 50mA at 5V, you need a supply impedance no higher than 4.6kΩ (230V ÷ 50mA).You then need to calculate the capacitor value which has this impedance at 50Hz. In this case, the result is 692nF.

Incidentally, the SILICON CHIP Reactance Wallchart (see page 76 in this issue) makes working out these values delightfully easy.

Since this is a minimum and you need some headroom to allow for lower mains voltage and losses (from R1, BR1 etc) you would go for a minimum of 820nF. We suggest that in this case, 1µF would be more appropriate, to allow for mains voltage variations, capacitors which are supplied slightly under-value etc.

Currawong volume control pot value

I've recently taken delivery of the Currawong stereo valve amplifier kit (November 2014-January 2015; siliconchip.com.au/Series/277) from Altronics. The original article specifies a 20kΩ motorised pot for volume control.

Altronics have supplied a 5kΩ pot. How will this affect performance? Is it worth buying a 20kΩ motorised pot from Alps? (C. B., Gillieston Heights, NSW)

● That will give a frequency response of -3dB at 20Hz and around -1dB at 40Hz. We doubt you will notice the difference. If you're concerned, you could simply increase the values of the 1.5µF input coupling capacitors to 4.7-10µF (eg, by using a bipolar electrolytic capacitor).

Hand Controller PCB question

Could you please tell me if PCB 05104073 (Programmable Ignition System Hand Controller PCB, SILICON CHIP Cat SC3007) is the same as PCB 05car141, which is the Hand Controller for the Digital Pulse Adjuster in your *Performance Electronics for Cars* book?

Jaycar has some of the kits from that magazine, including the Digital Pulse Adjuster but not the hand Controller. (I. L., Kandanga, Qld)

● The two PCBs are similar. The Hand Controller PCB we stock, from the March-June 2007 Programmable Ignition System (siliconchip.com.au/Series/56) includes room for six 330Ω resistors that connect from pins on the DB25 connector (6, 8 and 10-13) to ground. See page 67 of the April 2007 issue for the revised circuit.

It is recommended that you incorporate these extra resistors if you experience problems with corrupted characters on the hand controller display. So yes, you can use the 05104073 PCB as the Hand Controller for the Digital Pulse Adjuster.

Arduino-based GPS data logger wanted

I would be interested in constructing a project based on either of the VK2828U7G5LF or Neo-7M GPS modules described in the October 2017 issue of SILICON CHIP (El Cheapo Modules 10; siliconchip.com.au/Article/10827).

But at 62, I haven't used a soldering iron for over 40 years and have no knowledge of electronics with respect to being able to design the desired circuitry myself.

I am therefore writing to ask whether it might be possible to either develop a fully-fledged project using both of the modules in the subject article to pro-

...continued page 104

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Coming up in Silicon Chip

Altium Designer 2018 review
We have been using Altium Designer to develop circuits and design PCBs for many years now. In that time, quite a few improvements have been made to the software. We'll describe the new features and also point out some of the pre-existing features that have been improved or are particularly useful.

Introduction to programming the Cyprus CY8CKIT
This low-cost module incorporates a 32-bit microcontroller and a set of reprogrammable analog circuitry which can be used for a wide range of tasks.

The Latest Agricultural Technology, Pt.2
In this issue we looked at agricultural robots. Next month we take a look at new farm technology developments from two Australian universities.

$LiFePO_4$-based Uninterruptable Power Supply
Part three of the article which will be published in the next issue puts the finishing touches on construction, testing and interfacing with a PC.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The July 2018 issue is due on sale in newsagents by Thursday, June 28th. Expect postal delivery of subscription copies in Australia between June 27th and July 13th.

Notes & Errata

6GHz+ Touchscreen Frequency Counter, October-December 2017: CON1 is described as an "SMB" connector in the text and an "SMD" connector in the parts list. It is an SMA right-angle through-hole female connector. Digi-Key Cat 931-1361-ND is suitable.

800W+ Uninterruptible Power Supply, May-June 2018: in Fig.1 on page 32 of the May issue, the wiring shown for RLY3 is wrong. A corrected block diagram has been published in this issue, on page 65.

Frequency switch, May 2018: the +11.4V filter capacitor is shown as 10µF on the circuit diagram (Fig.2, page 38) but it should be 100µF, as on the PCB overlay diagram and parts list.

USB Port Protector, May 2018: in the circuit diagram on page 58 (Fig.1), the base resistor of Q2 should be 10kΩ and LED1's series resistor should be 47kΩ to be consistent with the PCB.

Ask Silicon Chip
. . . continued from page 102

duce "plug and play" devices to create "CSV" files stored on an SD or micro SD card which can then be imported into a spreadsheet program such as Microsoft Excel, Apache OpenOffice Calc or similar.

My ideal project would not require any soldering but the finished unit would be able to operate sitting on the passenger's seat in my car during my return trips from Canberra to Sydney, say, with the card then being able to be read using a device such as the Jaycar Digitech "All-in-1 USB Card Reader" (XC-4926). (P. M., Karabar, NSW)

● We suggest you have a look at our Arduino Data Logger with GPS project from the August and September 2017 issues. That will do pretty much exactly what you want.

You can leave off the extra components for the analog and digital inputs and just fit the micro SD card module, GPS module and RTC module.

That's all pretty straightforward to wire up. See: siliconchip.com.au/Series/316

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USB I/O can be done easily with Arduino

I read the "Open-USB-IO" article in the October 2009 issue and it seems that it is just what I need. I wonder if it is still available as a ready-made module or as a kit of parts. A bare PCB would also be helpful if one is available. (K. G., Newcastle, NSW)

● That project is now obsolete. However, USB I/O can be easily done with just about any Arduino board. It's cheaper than building a custom board, and you can add shields for isolated I/O, relay drivers etc.

Freely downloadable software already exists to turn an Arduino into a universal I/O device. Here is one example: https://code.google.com/archive/p/ioduino/ SC

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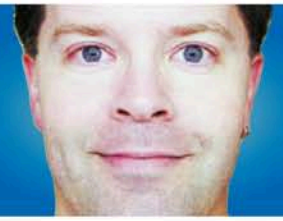

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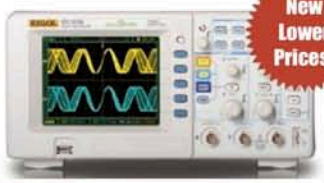

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PP-10HD - Workshop Hydraulic Press

- 10 Tonne
- Bench mount
- 180mm ram stroke
- Adjustable ram position

$319 ~~$352~~ (P141)

PLUS-8 - Industrial Bench Grinder with Linisher

- 200mm medium & coarse grit wheels
- 915 x 50mm linisher attachment
- 600W/ 0.8hp, 240V

$495 ~~$528~~ (G157)

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